TECHNICAL REPORT 98-2

PAVEMENT FRICTION IN INTERSECTIONS

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PAVEMENT FRICTION IN INTERSECTIONS

GOAL # 97-6

Goal:

By March 31, 1998, prepare a report documenting the pavement friction measurements obtained at intersections with high traffic volumes and hot mix asphalt pavements containing different aggregate rock types. Make recommendations on the next coarse of action.

Working Hypothesis:

The following have been established by previous research and subsequently verified. They form the basis on which this study is founded:

1. **Rock type of the coarse aggregate** in hot mix asphalt, and **traffic volume** are the two primary determinants of pavement friction [1,2,3].
2. For each aggregate rock type, or aggregate blend, there is a characteristic frictional response to various traffic volumes, determined using historical "open-road" friction data[4]. For any given traffic volume, a **minimum anticipated friction number (MAFN)** can be determined, based on this data. MAFN, for a given traffic volume, is herein defined as a friction number above which 90% of all historical "open-road" data fall. Refer to Appendix B for a detailed discussion of MAFN.

The following have been reported by others and have also been observed in test by request (TBR) sites and a PIL site (see Appendix C for a discussion and graphs). This study has been structured to obtain data related to these phenomena:

1. **Road geometry** (curves, grades, intersections) can have the effect of reducing friction [5].
2. **Braking effort** increases with proximity to the stop line [6] and this effort can have the effect of reducing friction.

1 Reference 1: Pavement Friction Inventory data with additional data gathered for Reference 5 were analyzed to establish this relationship.

2 Reference 2

3 Reference 9

4 References 1& 9: The 90% confidence line was used to predict "open-road" friction performance for various aggregates. "Open-road" conditions are level, tangent road sections posted at 40 mph or higher speeds. See Appendix B.

5 Reference 10: "there is a further reduction in skid resistance caused by the effect of turning and braking ....aggregates to be used in surfacings at most sites where traffic is turning or braking should have a psv (polished stone value- a static test of friction potential) at least 5 units higher than that which is indicated for similarly trafficked event-free sites in order to maintain the same level of resistance to skidding."

4 Reference 3: "there is no single deceleration trace. Some drivers brake hardest early, some late, some in the middle of the maneuver, and some brake at a near constant level throughout. However, when the data is summarized, the trend shows braking to increase with decreasing distance from the intersection."

3. **Road scum**, a combination of dust, petroleum drips, the products of petroleum combustion, and bits of tire rubber, may also lower pavement friction[1].

Findings:

1. Within the zones approaching the stop line, friction is lower within the braking zone (300' before the stop line, than in the entry zone (300' to 600' before the stop line)
2. There is no consistent relationship between friction in the entry zone (300' to 600' before the stop line) and that in either the turning or accelerating zones (beyond the stop line).
3. Average friction in entry zones (300' to 600' before the stop line) is significantly lower than anticipated by historic, "open road" testing in 4 out of 8 sites. These sites contained siliceous dolomite, traprock, Wappinger Dolomite, and Wappinger Dolomite/ granite blend.
4. Road scum was observed at each site and confirmed by examination of pavement cores. No quantification of either the oily or particulate components was attempted.
5. Average friction in the entry zone is below the programmatic design target minimum friction ($FN_{40} = 32$) in 4 of the 9 sites. These sites contained siliceous dolomite, limestone, Wappinger Dolomite, and a Wappinger Dolomite/ granite blend.

NOTE: Limestone was discontinued for use in top courses in 1969; Wappinger Dolomite was discontinued for use in top course, in roads with lane traffic volumes exceeding 4,000 vehicles per day, in 1992

Conclusions:

1. Pavement friction is consistently reduced as the stop line is approached, probably by a combination of the effects of vehicle braking and road scum contamination.
2. Vehicle turning and accelerating maneuvers may reduce pavement friction, but predictive relationships are unknown.
3. Historical "open-road" (Pavement Fiction Inventory) data cannot be used to predict friction within intersection areas.
4. The effect of road scum on pavement friction is unquantified.
5. Wappinger Dolomite/ granite blends and siliceous dolomite may not consistently provide design target friction ($FN_{40} = 32$) under high traffic (>4K LAADT) [2] intersection conditions.

Recommendations:

1. Continue current policy of response to friction data as delineated in the Memorandum of January 9, 1997 (see Appendix D).
2. Study aggregate friction under intersection conditions.

1 Reference 11: "In addition to loose particulate contamination (that reduces friction),...there are oils and lubricants, which cannot be easily removed."

Reference 4: "Oil is usually thought to promote slipperiness; it will do so if the oil layer has any significant thickness, The oil, rather than the water, then becomes the separating agent in the contact area and because of its higher viscosity, is more difficult to displace and for the irregularities (microtexture) to penetrate."

2 Reference 9: The demarcation between high and low traffic volume is based on the frictional performance of Wappinger Dolomite and other low insoluble residue dolomites.

Structure of the Study:

The study focuses on the measurement of pavement friction in intersection areas because the physics of traffic maneuvers is simpler there than in curves and on grades. To reduce geometric variables, selected intersections are right-angle, at-grade junctions of two roads. In addition, both intersecting roads have high traffic volumes (>4K LAADT), to maximize turning effects where they cross. Intersections were selected throughout the state to incorporate the widest possible variety of aggregate types. Friction measurements (adjusted to a standard 40 mph) were continuous, along a selected traffic lane, so that a friction profile could be constructed through the intersection area. For this study, intersection areas were divided into zones (see Figure 1):

1. **Entry zone** (600' to 300' before the stop line)
   1A. **Early entry zone** (600' to 450' before the stop line)
   1B. **Late entry zone** (450' to 300' before the stop line)
2. **Braking zone** (300' to 0' before the stop line) [1]
   2A. **Early braking zone** (300' to 150' before the stop line)
   2A. **Late braking zone** (150' to 0' before the stop line)
3. **Turning zone** (junction) (0' to 60' after the stop line)
4. **Accelerating zone** (60' after the stop line and beyond)

In addition to friction profiling each intersection, pavement cores were taken in the late braking zone of each lane tested. Coarse aggregate were extracted from the top course in each core and examined petrographically to determine aggregate rock type.

Data were selected from the historical friction data base (Pavement Friction Inventory [2] data supplemented by data obtained for Research Report 77 [3]), corresponding to each aggregate rock type found in the study. These data were used to construct plots of *Average Friction Number vs. Lane AADT* (average annual daily traffic for the lane tested). For each aggregate type, data were regressed into a "best-fit" line and 90% confidence lines, above and below. The lower line was to determine the minimum anticipated friction number (MAFN) for a given traffic volume. The MAFN allowed direct comparison between intersection friction data and open road data (see Appendix B for individual plots and a more detailed discussion of the MAFN).

The programmatic design target minimum (PDTM) friction number must be considered whenever friction aggregate specifications may be impacted. It is a friction number (32), measured at 40 mph with a drag-force trailer according to ASTM E 274 using a ribbed tire on the locked wheel. For highway design purposes, it is assumed that pavement surfaces have that friction [4].

1 Reference 3: this report identifies a distance of approximately 330' for braking as measured from the stop point, for vehicles traveling below 40 mph

Also Reference 6: At a design speed of 40 mph, and assuming a coefficient of friction of .32, measured at 40 mph, a minimum stopping distance of 275' to 325' is average for wet pavement.

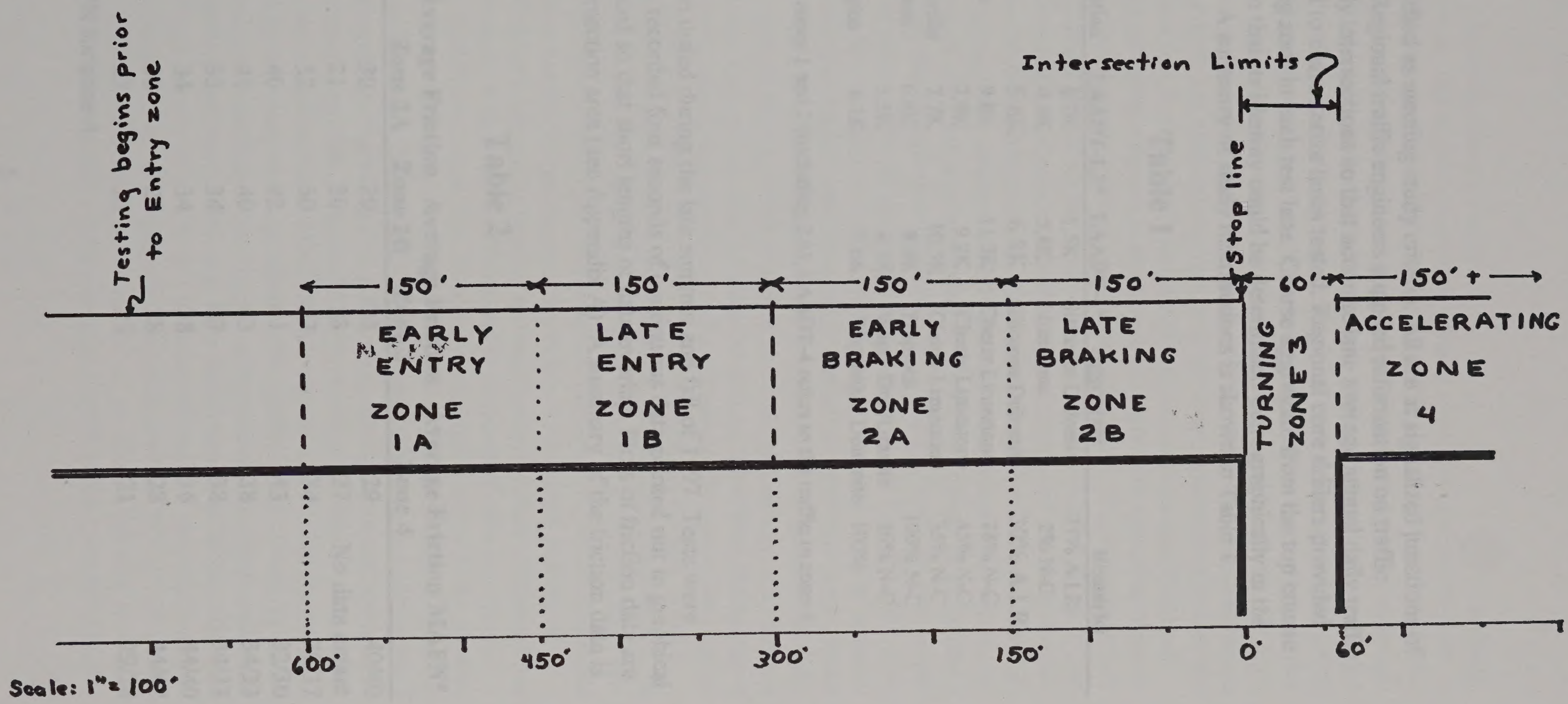
2 Reference 2: the Pavement Friction Inventory database

3 Reference 5: the database for the project reported in Research Report 77

4 Reference 6: the programmatic design target minimum friction number of 32, measured at 40 mph, that NYSDOT assumes for design purposes, is used this AASHTO design guide. It is the basis for deriving braking and maneuver sight distance and design speed in curves.

Figure 1

SCHEMATIC OF INTERSECTION TEST LANE COMPONENTS



Intersections selected:

Nine intersections were identified as meeting study criteria. All are at signalized junctions of two high traffic volume roads. Regional traffic engineers supplied information on traffic distribution patterns within study intersections so that accurate lane average annual daily traffic (LAADT) counts could be used to characterize lanes tested. Regional core drillers provided pavement cores from the braking zone in each test lane. Coarse aggregate from the top course was extracted from each core so that its identity could be determined petrographically in the Materials Bureau Geology Lab. A summary of study intersections is shown in Table 1.

Table 1

Site No.	Junction	Region/Location	LAADT-1,2*	LAADT-4*	Aggregate	Remarks
IF-1	Rt.5/Rt.155	1- Colonie	4.7K	5.5K	Siliceous Dolomite	21% A.I.R.
IF-2	Rt.5/Rt.11	3- Syracuse	4.6K	5.8K	Limestone	2% N-C
IF-3	Rt.250/Rt.441	4- Penfield	5.6K	6.8K	Siliceous Dolomite	30% A.I.R.
IF-4	Rt.65/Rt.252	4- Rochester	9.8K	11.3K	Cherty Limestone	28% N-C
IF-5	Rt.5/Rt.98	4- Batavia	7.9K	9.2K	Cherty Limestone	45% N-C
IF-6	Rt.5/Rt.78	5- Williamsville	7.7K	10.5K	Cherty Limestone	35% N-C
IF-7	Rt.25/Rt.110	10- Huntington	6.6K	8.9K	Traprock	100% N-C
IF-8	Rt.25A/GlenC.	10-Roslyn	3.5K	4.3K	Wapp. Dol./Granite	26% N-C
IF-9	Rt.25A/Rt.101	10- Kensington	6.1K	7.6K	Wappinger Dolomite	100%

* LAADT-1,2 refers to the traffic in zones 1 and 2 (including 2A); LAADT-4 refers to the traffic in zone 4

Testing

All intersections were friction tested during the late summer and fall of 1997. Tests were conducted at 40 mph; each test recorded four seconds of continuous data printed out in graphical form. Individual tests were spaced so that short lengths of data overlap. Plots of friction data are continuous throughout the intersection area (see Appendix A). A summary of the friction data is shown in Table 2.

Table 2

Site No.	Average Friction Zone 1A	Average Friction Zone 1B	Average Friction Zone 2A	Average Friction Zone 2B	Average Friction Zone 3	Average Friction Zone 4	MAFN*
IF-1	31	31	30	29	31	29	40/40
IF-2	22	23	21	20	23	27	No data extant
IF-3	55	55	52	50	53	34	39/37
IF-4	43	40	40	42	41	43	32/30
IF-5	45	44	41	40	43	38	34/33
IF-6	35	38	35	34	37	38	34/33
IF-7	35	35	34	34	38	36	44/40
IF-8	31	30	30	29	28	28	44/42
IF-9	24	24	23	23	23	21	29/28

* MAFN for zones 1, 2 / MAFN for zone 4

Analysis:

Within each site, average friction was compared among zones. Not only are different maneuvers encountered (braking, turning, accelerating), but variation in braking effort is represented within the braking zone. Both approach zones were divided to make four zones, two in the entry zone and two in the braking zone. By examining four zones, instead of two, frictional relationships can be analyzed in more detail. Also, by comparing friction in zone 1A with that in zone 2B, a greater distinction can be drawn between entry zone conditions and braking zone conditions. Indeed, frictional relationships between zones were identified and those relationships were compared among sites.

Because there are various aggregate rock types represented within study test sites, it is not possible to compare average friction numbers, one site to another. Rather, a minimum anticipated friction number (MAFN) for each aggregate rock type was established (as explained above and in Appendix B) for comparison to "open-road" performance. In the particular case of siliceous dolomites, data does not show a correlation between friction number and traffic volume. It was determined, nevertheless, that, for this rock type, no data fall below a friction number of 40, so this number was selected as the MAFN for siliceous dolomite (Appendix B, figures B-1 and B-3). Comparison of the MAFN to the average friction number for the entry zone provides an opportunity to draw inferences about similarity or dissimilarity between the two conditions. The entry zone for each site is a flat, tangent section, in which traffic performs minimal turning, braking, or accelerating maneuvers. Therefore, in terms of road geometry and traffic flow, the entry zone is similar to historical "open-road" sites. Significant deviation of site friction, particularly entry zone friction, from "open-road" friction is indicated when average friction numbers are significantly less than MAFNs.. Initially, it was believed that entry zone conditions would prove essentially equivalent to open road conditions. It was intended that site testing would begin were intersection conditions had not affected pavement friction.

1. When friction in entry zone 1A is compared to that in braking zone 2B, the zones that should exhibit the most consistent relationship if braking maneuvers have a reduction effect on friction, it was found that in all nine sites the friction in zone 1A is greater than in zone 2B. Differences were anticipated to be greater (differences range from 1 to 5 friction numbers).

2. In general, friction in turning and accelerating zones bear no relationship with that in entry and braking zones. No conclusions can be drawn from the data in these zones.

3. Friction in entry zones are below the MAFN in 4 of the 8 sites for which a MAFN can be determined. A relationship between MAFN and entry zone friction is implied by the assumed similarity in geometry and traffic flow between "open road" conditions and entry zone conditions. If entry zone conditions are equivalent to "open road" conditions, entry zone friction should seldom fall below the MAFN, since 90% of "open road" friction should exceed the MAFN. The e MAFN is used as a surrogate for true "open road" friction measurement in the proximal vicinity of each intersection wherein the top mix is the same throughout. Appendix C contains a friction profile (Figure C-5) of a PIL (priority investigation location) on Rt 9, in Poughkeepsie, that demonstrates linkage between true "open road" conditions and intersection conditions. Friction testing of this site was extended to 0.6 mile before the first signalized intersection in the northbound lanes. The profile includes a MAFN of 40 for the aggregate (Wappinger Dolomite/ granite blend, >30% non-carbonate) and traffic volume (9.5 K driving lane AADT). At this site, friction is near the MAFN up to 0.2 mile from the first intersection. Friction appears to be reduced within at least 0.1 mile before this intersection, a distance that includes both the entry and braking

zones (600' before the stop line) , as defined for this study.

4. Road scum was observed at each site and on the surface of each pavement core taken from the late braking zones. The mere presence of oily residues is no proof of a road scum effect. Some minimum film thickness is required to induce friction reduction [1], and no investigator has suggested a method of measurement.

Discussion of Each Intersection:

Each study intersection is represented by figures showing a friction profile (Appendix A), and a plot of Friction Number vs. Lane AADT for the aggregate type in each intersection (Appendix B). Each minimum anticipated friction number (MAFN) is derived from plots in Appendix B and are shown, for comparison, as horizontal lines in Appendix A friction profiles. Schematic diagrams of each intersection is shown in Figure 2. Appendix C includes long road sections tested every 0.1 mile, as TBRs, and are discussed later.

Each of the following discussions include comparison to the programmatic design target minimum (PDTM) of 32 (a friction number determined at 40 mph). This number is used in basic highway design[1] ; NYSDOT specifies aggregates that will provide pavements that will meet or exceed that minimum. The Pavement Friction Inventory is part of a FHWA mandated [2] program to monitor NYSDOT aggregate specification performance.

IF-1:

This intersection is located at the junction of routes 5 and 155 in the Town of Colonie. Lane 2, westbound on Rt. 5 was selected for testing. Traffic in this area is generally slow, moving through a series of signalized intersections. Test lane AADT in the entry and braking zones is approximately 4.7K vehicles per day and approximately 5.5K vehicles per day in the accelerating zone. This disparity is to be expected where dedicated turning lanes draw traffic out of through lanes. Coarse aggregate in the top course is siliceous dolomite having an acid insoluble residue content [3] of 21%, well within the specification limit of 17% for dolomites as friction aggregates (1995 change). The MAFNs for this aggregate are both about 40, for the two traffic levels.

Average friction measured within each of the four zones was between 31 and 29 (see Table 2). These are well below the MAFN and is also below the programmatic design target minimum (PDTM) of 32. Braking zone friction was found be lowest, which might have been anticipated, but matched by that in the accelerating zone, where there is slightly higher traffic.

IF-2:

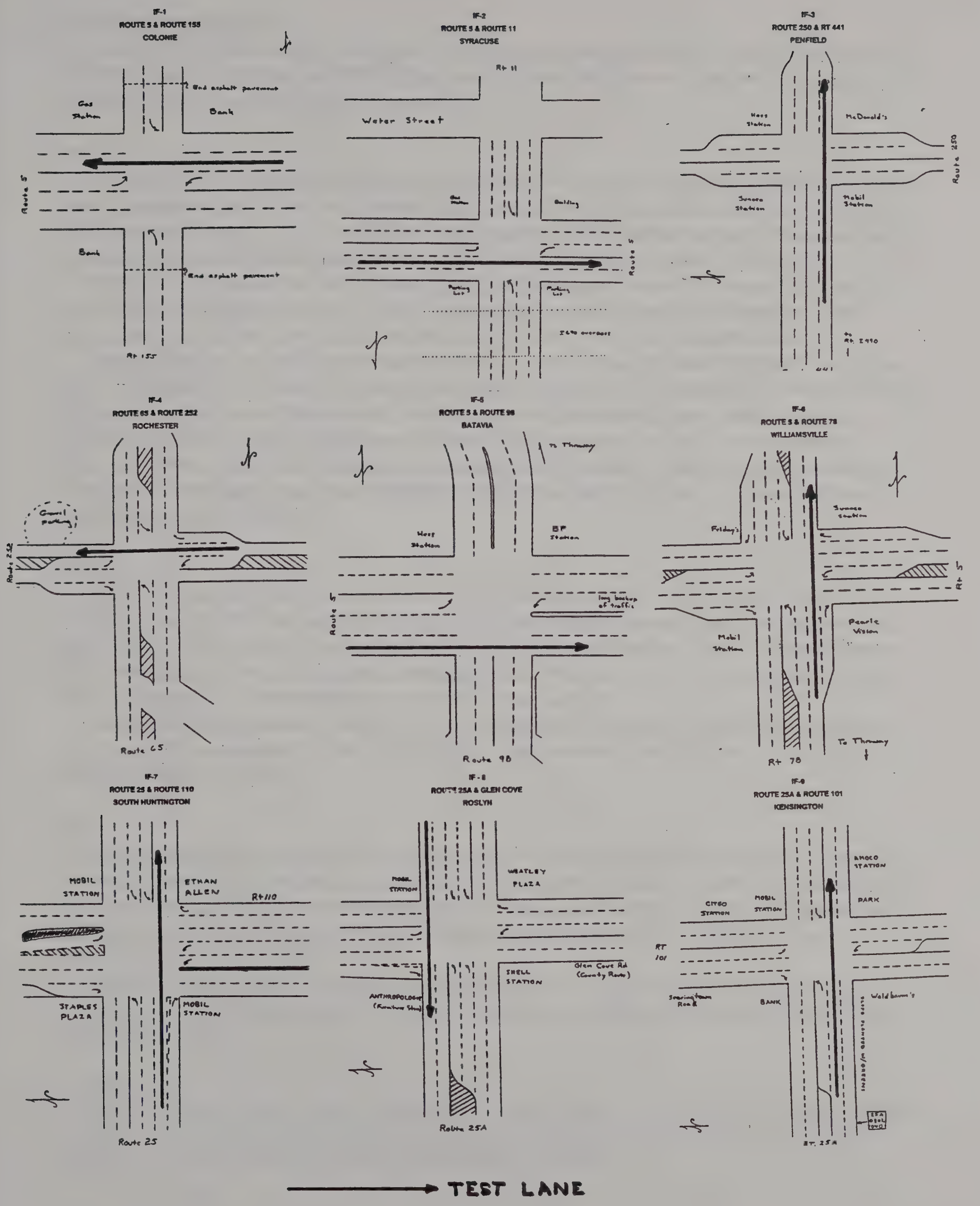
This intersection is located within the City of Syracuse at the junction of routes 5 and 11. Lane 2, westbound on Rt.5 was selected for testing. As in IF-1, traffic is generally slow, moving through a series of signalized intersections. Test lane AADT is approximately 4.6K vehicles per day in entry and braking zones and approximately 5.8K vehicles per day in the accelerating zone. Coarse aggregate in the top course is limestone contaminated with approximately 2% non-carbonate material. Asphalt top mixes containing essentially pure limestone coarse aggregate have not been used in state contracts since the 1960s; there is no historical "open road" friction data

1 Reference 6: AASHTO design guidelines

2 Reference 7: FHWA *Skid Accident Reduction Program*

3 Reference 8: NYSDOT Test Method 703-13G

Figure 2


IF-1
ROUTE 5 & ROUTE 155
COLONIE
End asphalt pavement
Gas Station
Bank
Route 5
Bank
End asphalt pavement
Rt 155
IF-2
ROUTE 5 & ROUTE 11
SYRACUSE
Rt 11
Water Street
Building
Route 5
Parking Lot
Parking Lot
I690 overpass
IF-3
ROUTE 250 & RT 441
PENFIELD
Hess Station
McDonald's
Route 250
Sunoco Station
Mobil Station
to Rt I490
441
IF-4
ROUTE 65 & ROUTE 252
ROCHESTER
Gravel Parking
Route 252
Route 65
IF-5
ROUTE 5 & ROUTE 98
BATAVIA
To Thruway
Hess Station
BP Station
Route 5
long backup of traffic
Route 98
IF-6
ROUTE 5 & ROUTE 78
WILLIAMSVILLE
Friday's
Sunoco Station
Rt 5
Mobil Station
Pearle Vision
Rt 78
To Thruway
IF-7
ROUTE 25 & ROUTE 110
SOUTH HUNTINGTON
MOBIL STATION
ETHAN ALLEN
Rt 110
STAPLES PLAZA
MOBIL STATION
Route 25
IF-8
ROUTE 25A & GLEN COVE
ROSLYN
MOBIL STATION
WEATLEY PLAZA
SHELL STATION
Glen Cove Rd (County Route)
ANTHROPOLOGIE (Furniture Store)
Route 25A
IF-9
ROUTE 25A & ROUTE 101
KENSINGTON
AMOCO STATION
CITGO STATION
MOBIL STATION
PARK
RT 101
Searingtown Road
BANK
Waldbaum's
RT. 25A
TEST LANE

available for comparison.

Average friction measured within each of the four zones was between 27 and 20 (see Table 2), all of which are well below the PDTM. Late braking zone friction was found to be lowest, where individual friction numbers were as low as 19.

IF-3:

This intersection is located at the junction of routes 441 and 250 within the Village of Penfield. Lane 1, eastbound on Rt. 441 was selected for testing. This lane is used almost exclusively for right turns and has a LAADT of approximately 5.6K vehicles per day. The accelerating zone receives not only through traffic, but traffic turning left from Rt. 250, resulting in an LAADT of 6.8K vehicles per day. Coarse aggregate in the top course is siliceous dolomite with an acid insoluble residue content [1] of 30%, well within acceptable limits for dolomite friction aggregate. The MAFNs for siliceous dolomite are 39 and 37, for the two traffic levels.

Average friction measured within each of the four zones varied between a high of 55 to a low of 34 (see Table 2). Friction in the entry zone was the highest at 55, dropping to 50 within the late braking zone. The lowest friction was found to be in the accelerating zone, where there is a dramatic increase in traffic. Caution must be exercised in interpreting this dramatic drop in friction, however, as the accelerating zone was not cored to confirm coarse aggregate identity. Only in the accelerating zone does the friction drop below the MAFN of 37, although it does remain above the PDTM of 32.

IF-4:

This intersection is at the junction of routes 252 and 65 in the City of Rochester. Lane 1, westbound on Rt. 252, was selected for testing. It carries approximately 9.8K vehicles per day in the entry and braking zones, and approximately 11.3 in the accelerating zone. Coarse aggregate in the top course is cherty limestone containing about 28% chert (a form of quartz also known as flint). The MAFN was determined to be about 31 (see Table 1).

Average friction measured in the four zones varied from a high of 43, in the accelerating zone, to a low of 38, unexpectedly in the early braking zone. Nowhere does the friction fall below the MAFN or below the PDTM.

IF-5:

This intersection is located at the junction of routes 5 and 98 in the City of Batavia. Lane 1, eastbound was selected for testing. It has a LAADT of approximately 7.9K vehicles per day in the entry and braking zones, and approximately 9.2K in the accelerating zone. Coarse aggregate in the top course is cherty limestone having a chert content of about 45%. The MAFN was determined to be about 33 (see Table 1).

Average friction measured in the four zones varied from a high of 44, in the entry zone, to a low of 38, in the accelerating zone. Average friction numbers for each zone are above both the MAFN [2] and PDTM.

1 Reference 8

2 "Open-road" conditions dictate that measured friction is greater than the MAFN, with 90% confidence, because the MAFN is derived from the 90% confidence line (see Appendix B). That friction is above the MAFN tells nothing about frictional performance in other than "open-road" conditions.

IF-6:

This intersection is located at the junction of routes 78 and 5 in the Village of Williamsville, a suburb of Buffalo, just north of a N. Y. State Thruway exit. Lane 1, northbound on Rt. 78, was selected for testing. Traffic volume south of the junction, in the entry and braking zones is approximately 7.7K vehicles per day, and approximately 10.5K in the accelerating zone. Coarse aggregate in the top course is cherty limestone having a chert content of about 45%. The MAFNs were determined to be about 34 and 33, for the two traffic levels (see Table 1).

Average friction measured in the four zones varied from a high of 38, in both the late entry accelerating zones, to a low of 34, in the late braking zone. The unexpected spike in friction in the late entry zone may be a local anomaly. There are individual friction measurements as low as 32, just about at the MAFN and PDTM (see Appendix A).

IF-7:

This intersection is located at the junction of routes 25 and 110 in Huntington, Nassau Co., LI. Lane 1, eastbound on Rt.25 was selected for testing. The traffic volume west of the junction, in the entry and braking zones, is approximately 6.6K vehicles per day, and approximately 8.9K in the accelerating zone. Coarse aggregate in the top course was found to be 100% traprock, a crystalline, non-carbonate material. The MAFNs were determined to be about 44 and 40, for the two traffic levels (see Table 1).

Average friction measured in the four zones range from a high of 38, in the turning zone, to a low of 34 in both the early and late braking zones. Individual low friction numbers of 32 and 28 were measured within the late braking zone and acceleration zone, respectively (see Appendix A). The average friction numbers are all below the MAFN but above the PDTM.

IF-8

This intersection is located at the junction of Rt. 25A and Glen Cove Rd. in Roslyn, Nassau Co., LI. Lane 1, westbound on Rt. 25A, was selected for testing. The traffic volume east of the junction, in the entry and braking zones, is approximately 3.5K vehicles per day, and approximately 4.3K in the accelerating zone. Coarse aggregate in the top course is a blend of Wappinger Dolomite and granite, having a non-carbonate content of 26%. The MAFNs were determined to be 44 and 42, for the two traffic levels (see Table 2).

Average friction measured in the four zones range from a high of 31, in the entry zone, to a low of 28 in the turning and accelerating zones. Individual friction measurements of 25 were recorded in the accelerating zone. All friction averages are below the MAFN and the PDTM.

IF-9:

This intersection is located at the junction of Rt. 25A and Searingtown Road in Kensington, Nassau Co., LI. Lane 2 eastbound on Rt. 25A was selected for testing. The traffic volume west of the intersection, in the entry and braking zones, is approximately 6.1K vehicles per day, and approximately 7.6K in the accelerating zone. Coarse aggregate in the top course was 100% Wappinger Dolomite. The MAFNs are about 29 and 28, for the two traffic levels (see Table 2).

Circumstances prevented the continuous friction measurement of this intersection as at the other eight. Eight spot average friction measurements were taken throughout the four zones ranging from a high of 24, in the entry zone, to a low of 21 in the accelerating zone. All measurements are below the MAFN and the PDTM.

Other Friction Data:

Appendix C contains a discussion of TBR data and its relationship to this study.

Appendix C also contains a friction profile of a portion of a PIL on Rt 9, Poughkeepsie which represents both "open road" and intersection data.

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4. NCHRP Synthesis, ***Skid Resistance***, Synthesis of Highway Practice 14, 1972

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11. Dahir, S. H., and Henry, J. J., ***Seasonal and Short-Term Variations in Skid Resistance***, TRR 715, 1979

APPENDIX A

APPENDIX A

FRICTION PROFILES

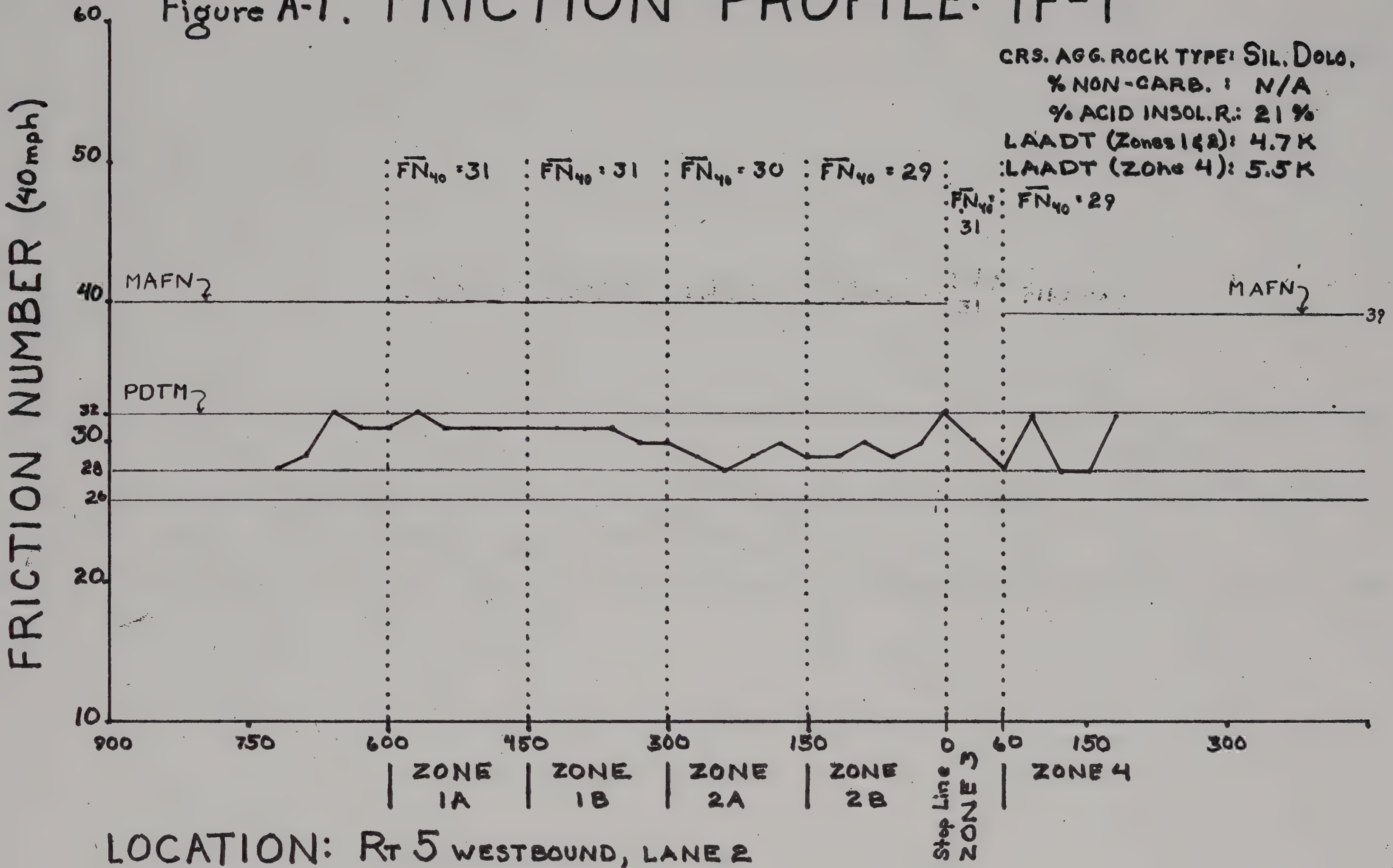
Each intersection in the study is represented by a friction profile. Except for IF-9, data were derived from continuous, 4-second graphical readouts of friction measured at 40 mph according to ASTM E 274 with a ribbed tire. IF-9 was developed from spot averages. Each test section contains 150' of friction data; test sections were spaced 60 feet apart so that there would be data overlap with contiguous sections. Friction was picked from the continuous readouts at half second intervals and combined with overlaps to yield a series of half second (or 30-foot) data points. These were plotted to produce these friction profiles.

Minimum anticipated friction numbers (MAFNs) were determined for aggregates at each intersection. The plots from which MAFNs were derived appear in Appendix B. MAFNs were added to each Friction Profile for comparison with "open road" friction.

The length of each test lane that was friction tested was determined by observation at each intersection. The distance from the junction where vehicle brake lights went on was noted so that testing would begin several hundred feet before. For the analysis, the division between the entry and braking zones was made 300 feet from the intersection stop line. The point at which braking begins varies from driver to driver[1]. Moreover, as the hourly traffic intensity changes, so does the number of vehicles stacked behind the stop line. The average distance from the stop line that vehicles begin braking may vary widely between those vehicles that stop close to the stop line and those that stop farthest back. However, according to Farber, et al [1], observed driver behavior shows braking begins about 330' from the stop line, on roads where prevailing speeds are 40 mph and below. <u>Moreover, Farber found braking effort is, overall, inversely related to a vehicle's distance from the stop line [1]</u>.

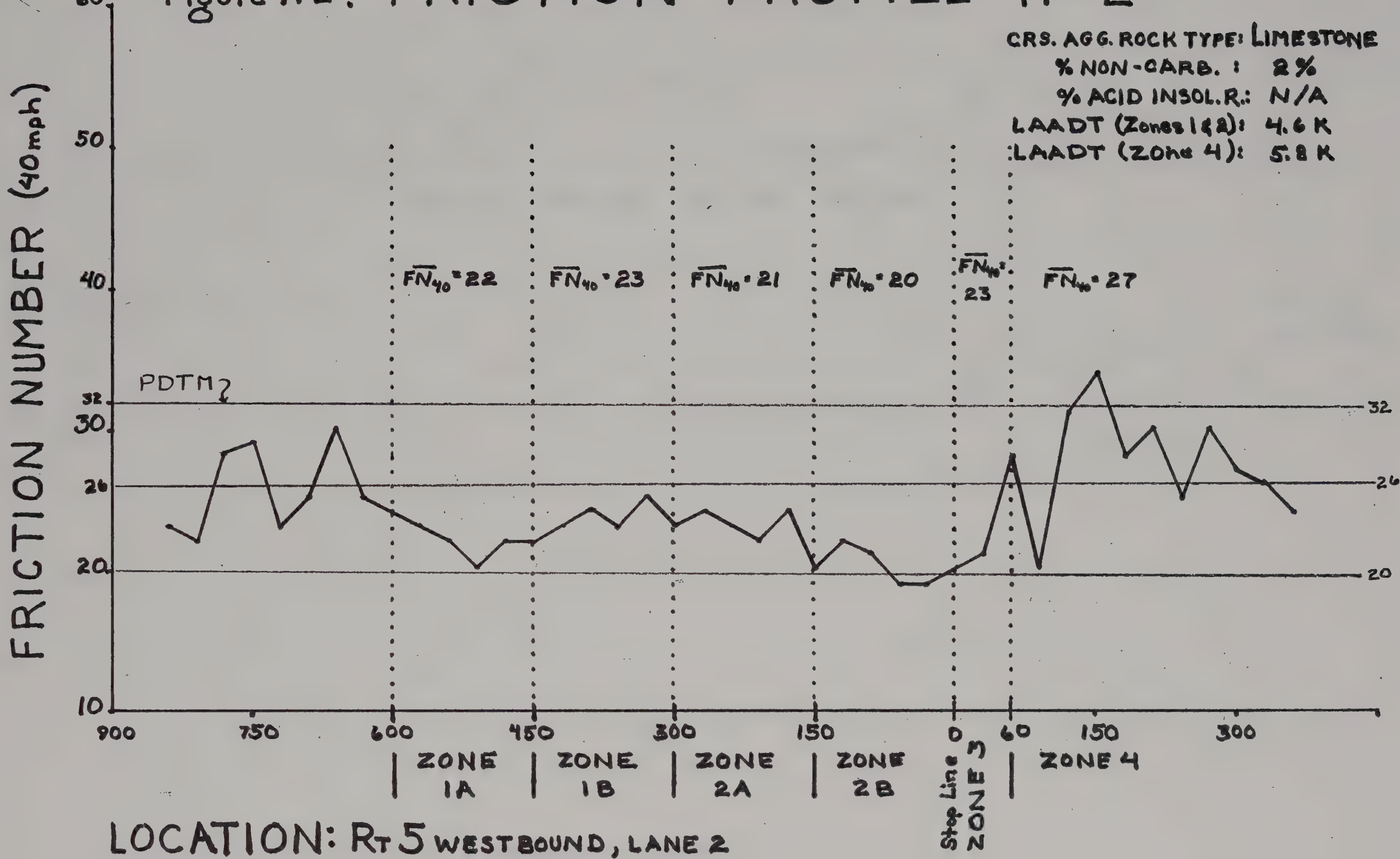
1 Reference 3: Farber, E. et al.

Figure A-1. FRICTION PROFILE: IF-1



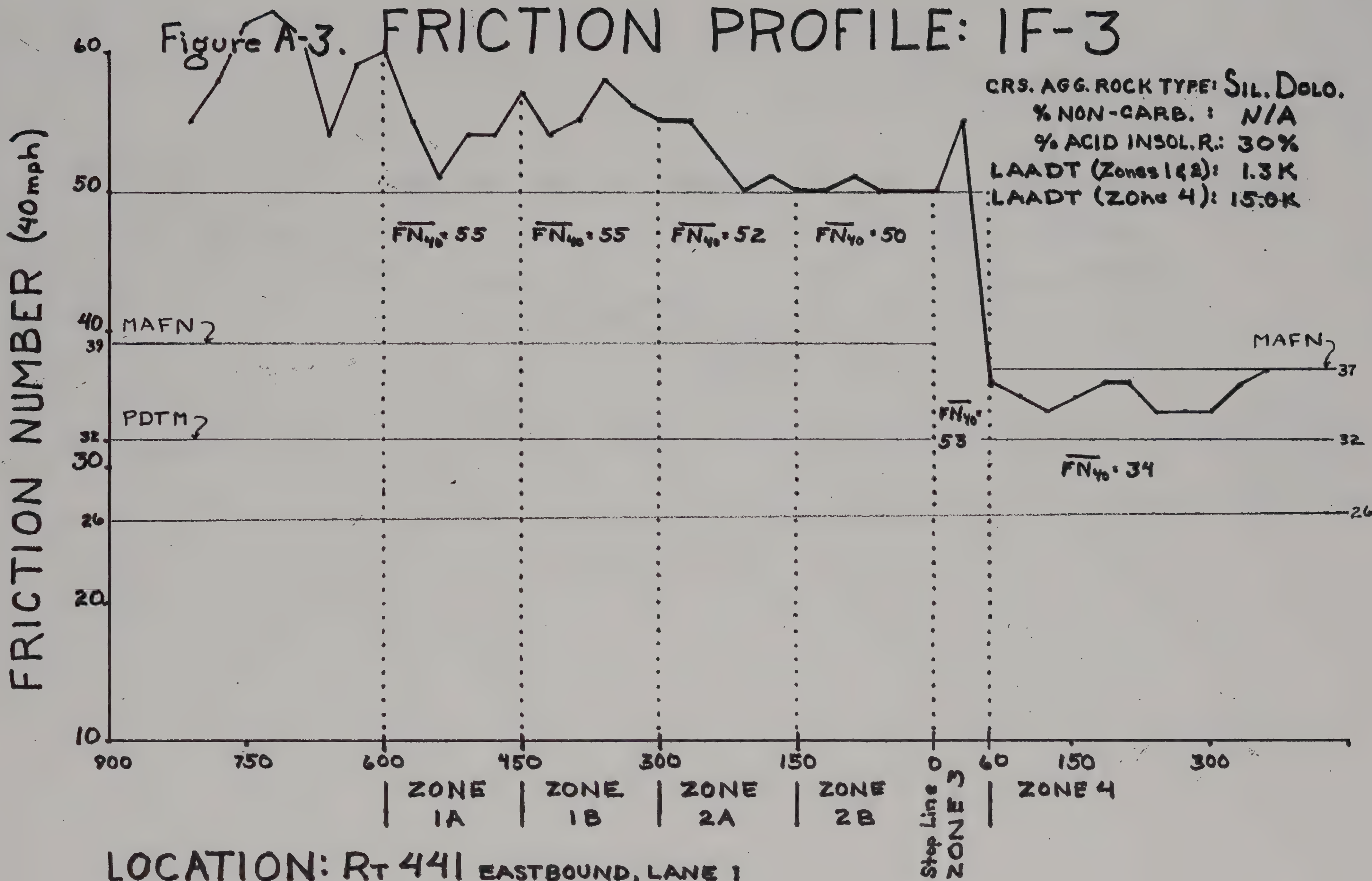
LOCATION: RT 5 WESTBOUND, LANE 2

Figure A-2. FRICTION PROFILE: IF-2



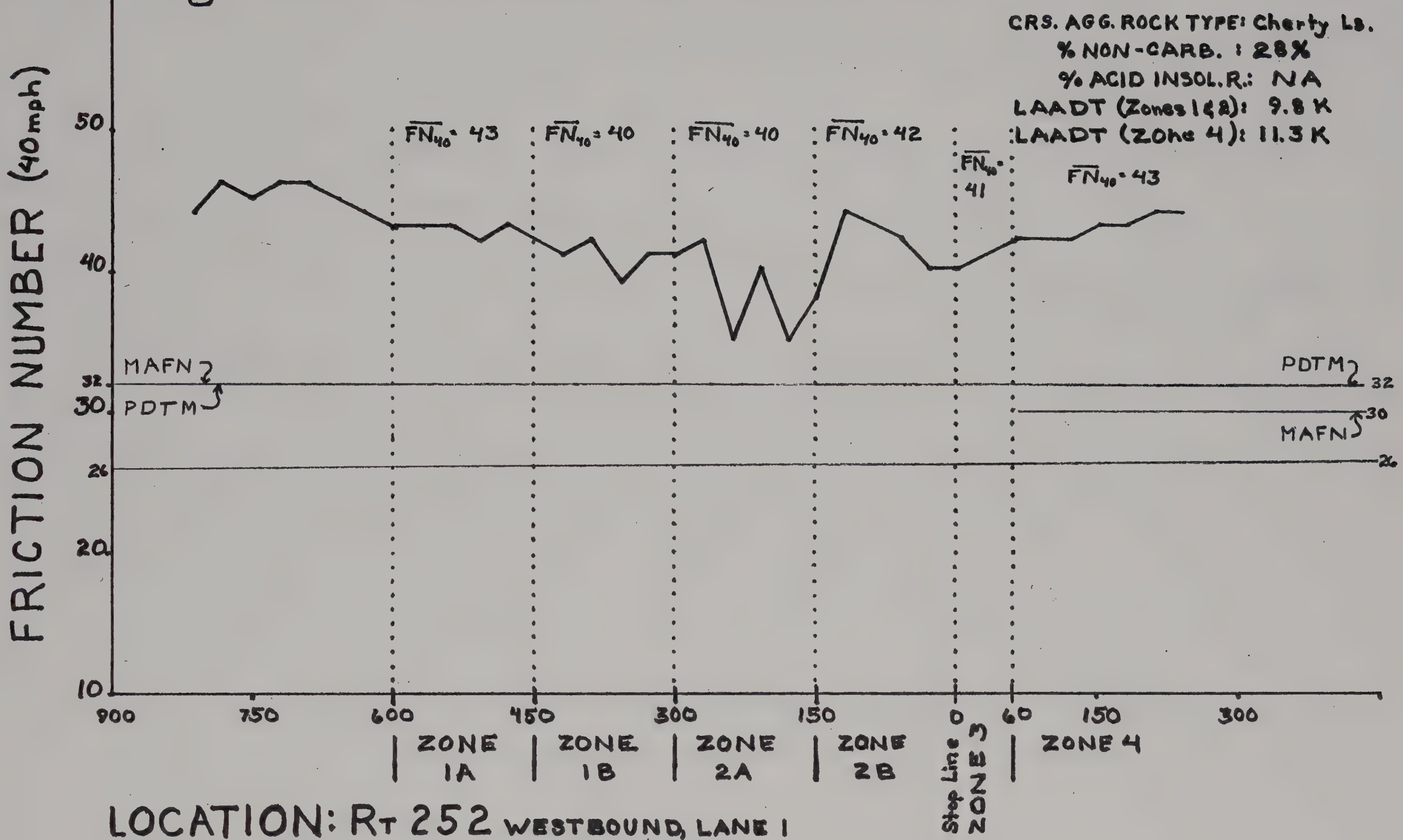
LOCATION: RT 5 WESTBOUND, LANE 2

Figure A-3. FRICTION PROFILE: IF-3



LOCATION: RT 441 EASTBOUND, LANE 1

Figure A-4. FRICTION PROFILE: IF-4



LOCATION: RT 252 WESTBOUND, LANE 1

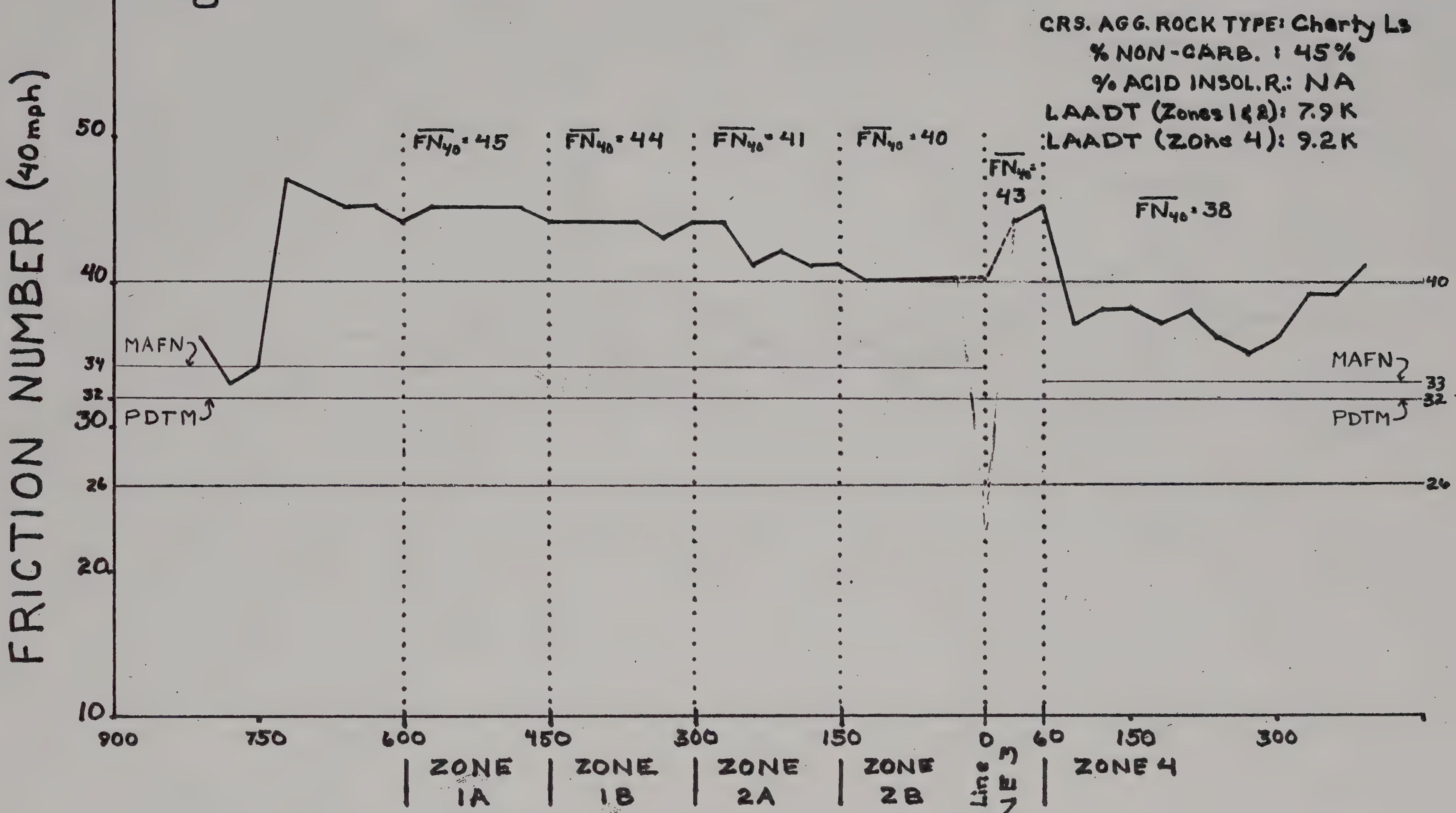
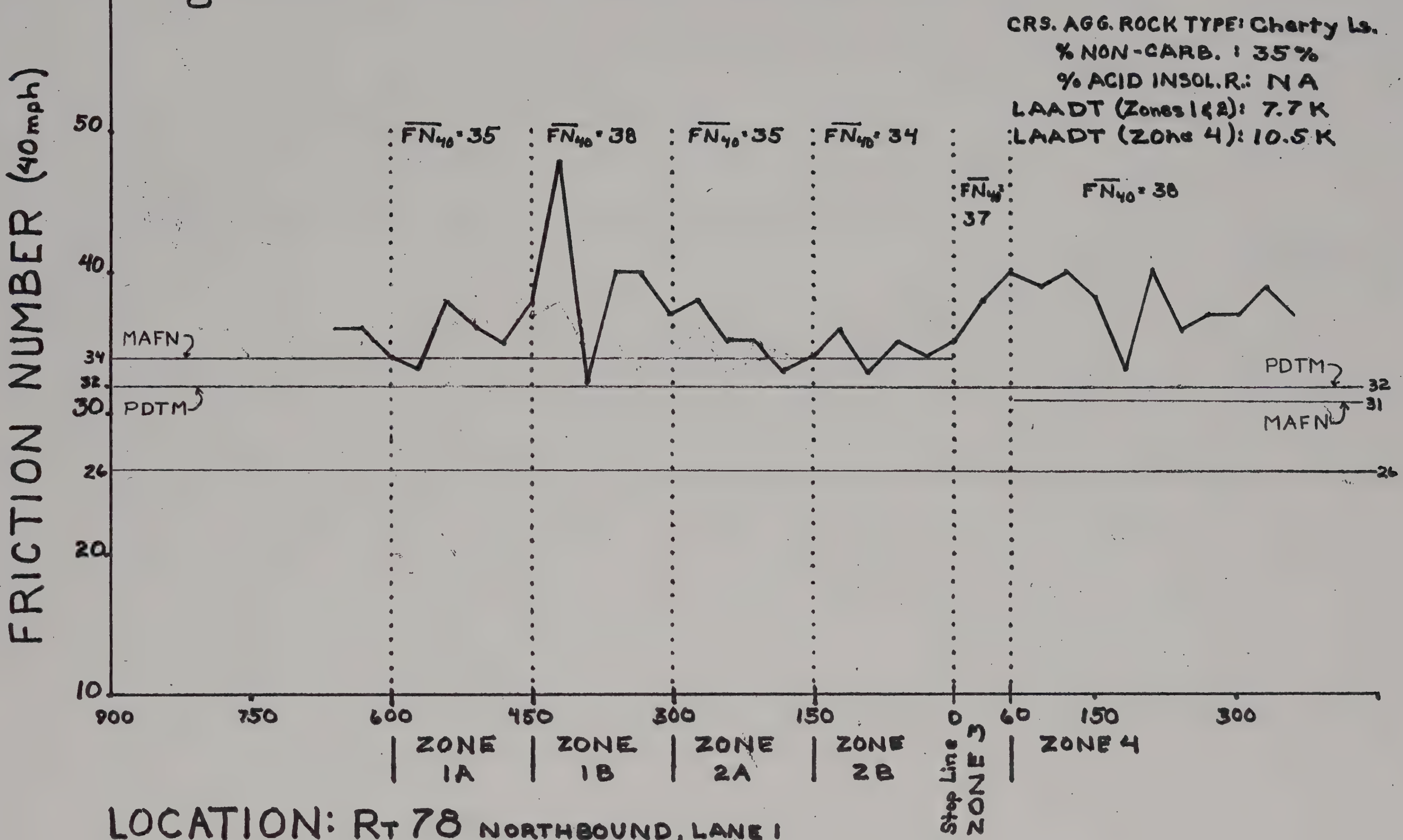


Figure A-5. FRICTION PROFILE: IF-5

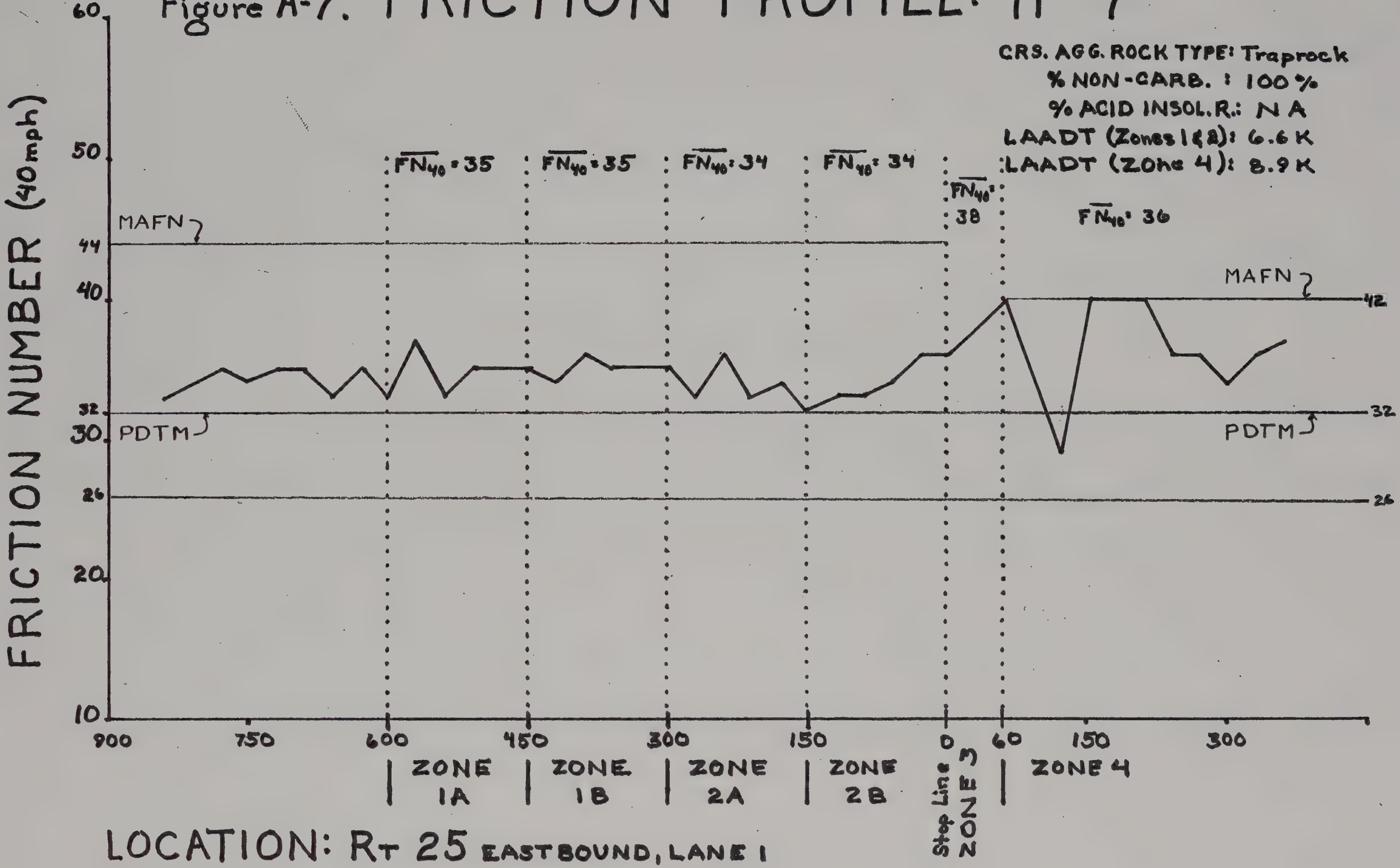
LOCATION: RT 5 EASTBOUND, LANE 1

Figure A-6. FRICTION PROFILE: IF-6



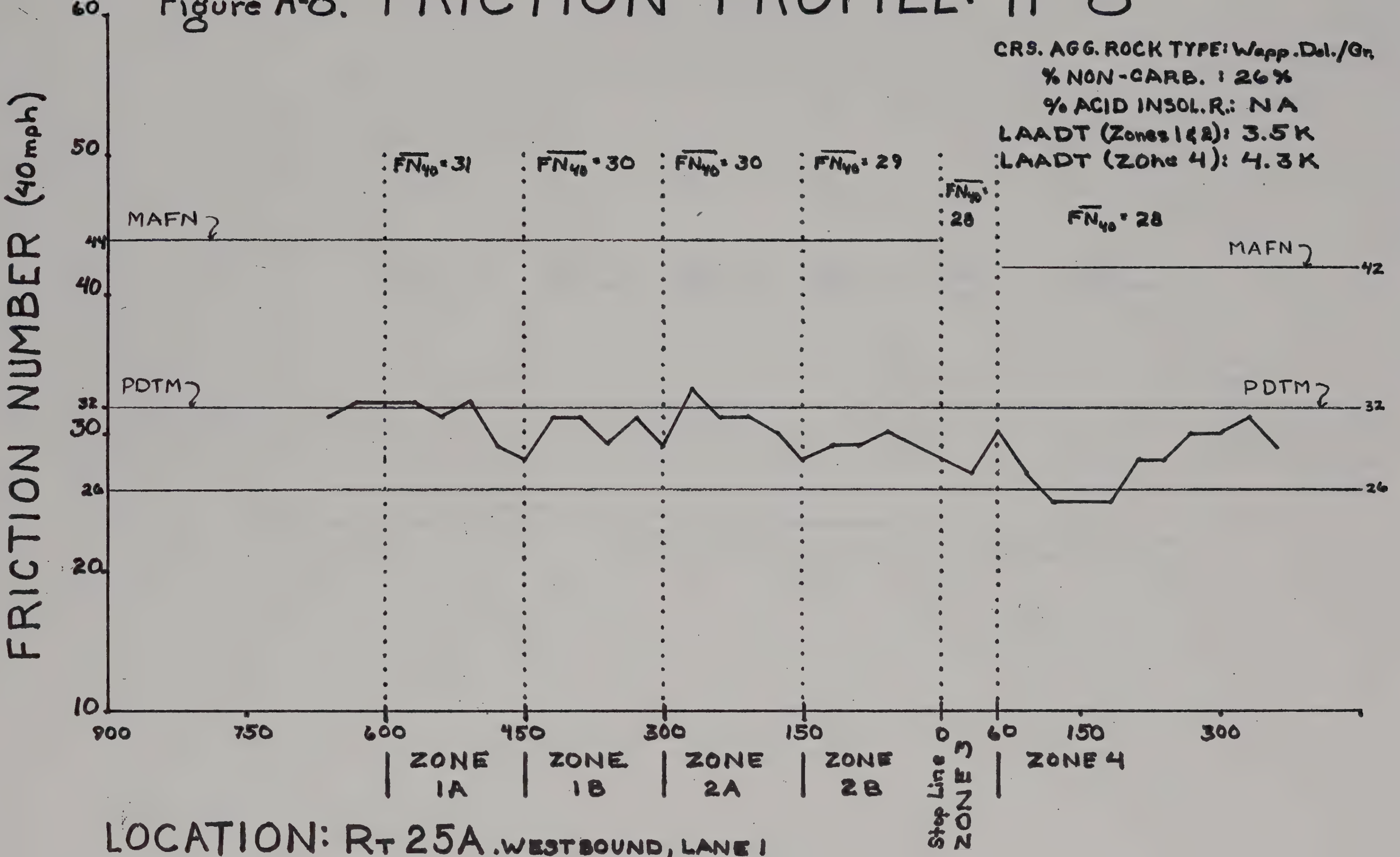
LOCATION: RT 78 NORTHBOUND, LANE 1

Figure A-7. FRICTION PROFILE: IF-7



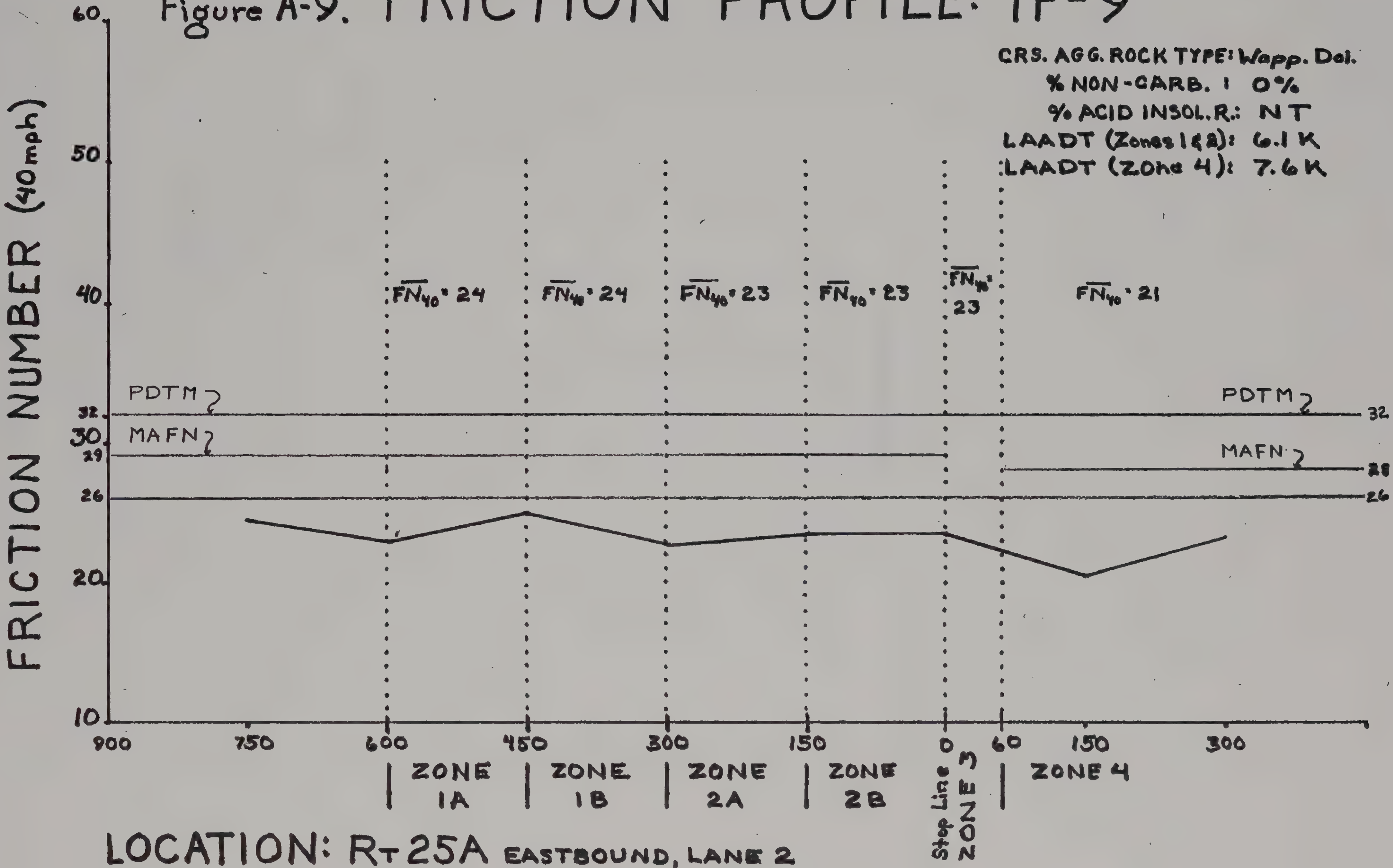
LOCATION: RT 25 EASTBOUND, LANE 1

Figure A-8. FRICTION PROFILE: IF-8



LOCATION: Rt 25A, WESTBOUND, LANE 1

Figure A-9. FRICTION PROFILE: IF-9



LOCATION: RT 25A EASTBOUND, LANE 2

APPENDIX B

APPENDIX B

MINIMUM ANTICIPATED FRICTION NUMBERS

This appendix contains plots of historical "open road" friction data obtained from the Pavement Friction Inventory and from friction measurements used as the basis for Research Report 77 [1]. There is no historical "intersection" friction data because it was believed "open road" conditions were no different from other geometric road conditions, in so far as affecting pavement friction. Placement of intersection friction data within the context of historical "open road" friction data suggests either similarity or dissimilarity, either of which are important. It had been envisioned that the entry zones were analogous to the "open road" conditions, and those friction measurements would fall within the field of data, for the aggregate and traffic volume, historically recorded for "open road" conditions. It was found that, in some intersections, all friction data fell below anticipated levels. The MAFN (minimum anticipated friction number) was developed to demonstrate the relationship between the "open road" data set and the data set fro each intersection.

For each intersection, aggregate identity was determined petrographically from material extracted from cores drilled in braking zones. Historical friction data was selected that best represents coarse aggregate at each intersection. Intersection IF-2 contains limestone, which has not been allowed in top courses, on state contracts, since the late 1960s. There is no historical data available from which to derive a MAFN for limestone.

Data was selected for each intersection and plotted to show Average Friction Number vs. Lane AADT. A "best-fit" regression line was drawn through the data points that best represents the average. The 90% confidence lines were drawn above and below the "best-fit" line. The lower line is the locus of points representing the minimum anticipated friction for this study. Lane AADTs for the lane tested at each intersection, are shown by vertical lines on these plots. The points at which these vertical lines intersect the 90% confidence line are friction numbers called MAFNs, for this study. Horizontal lines, representing MAFNs are drawn through the Friction Profiles in Appendix A. This allows for comparison of friction measured in intersection zones to be compared with minimum values in open road conditions.

NOTE: References 1 and 9 used historical "open-road" data plotted and analyzed as described above. MAFN is a term developed for this study.

Significance of Minimum Anticipated Friction Number:

MAFN neither represents an average friction number for an aggregate in "open-road" conditions, nor does it represent the range that may be anticipated when this aggregate is used. Rather, it represents the lower limit of anticipated "open-road" friction, for a given aggregate at a given traffic intensity, and ***provides a test for the applicability of friction aggregate specifications where road conditions are other than "open-road"***.

Figure B-1

AVERAGE FRICTION NUMBER vs

TRAFFIC INTENSITY (LAADT)

```
For MAFN determination for intersections IF-1 and IF-3:
IF-1   LAADT in zones 1 & 2= 4.7K   MAFN= 40
       LAADT in zone 4     = 5.5K   MAFN= 40
IF-3   LAADT in zones 1 & 2= 5.6K   MAFN= 39
                             6.8K   MAFN= 37
```

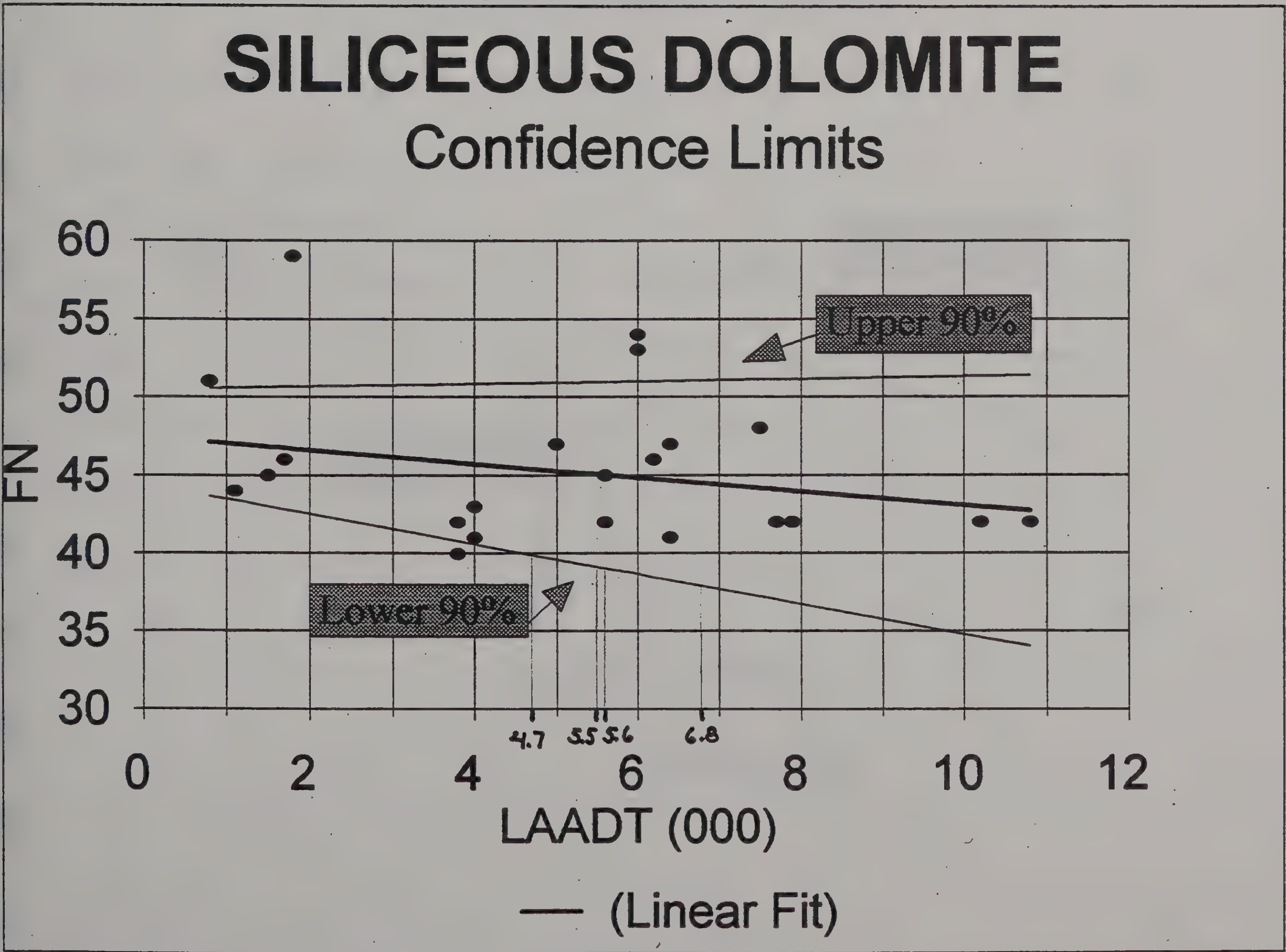
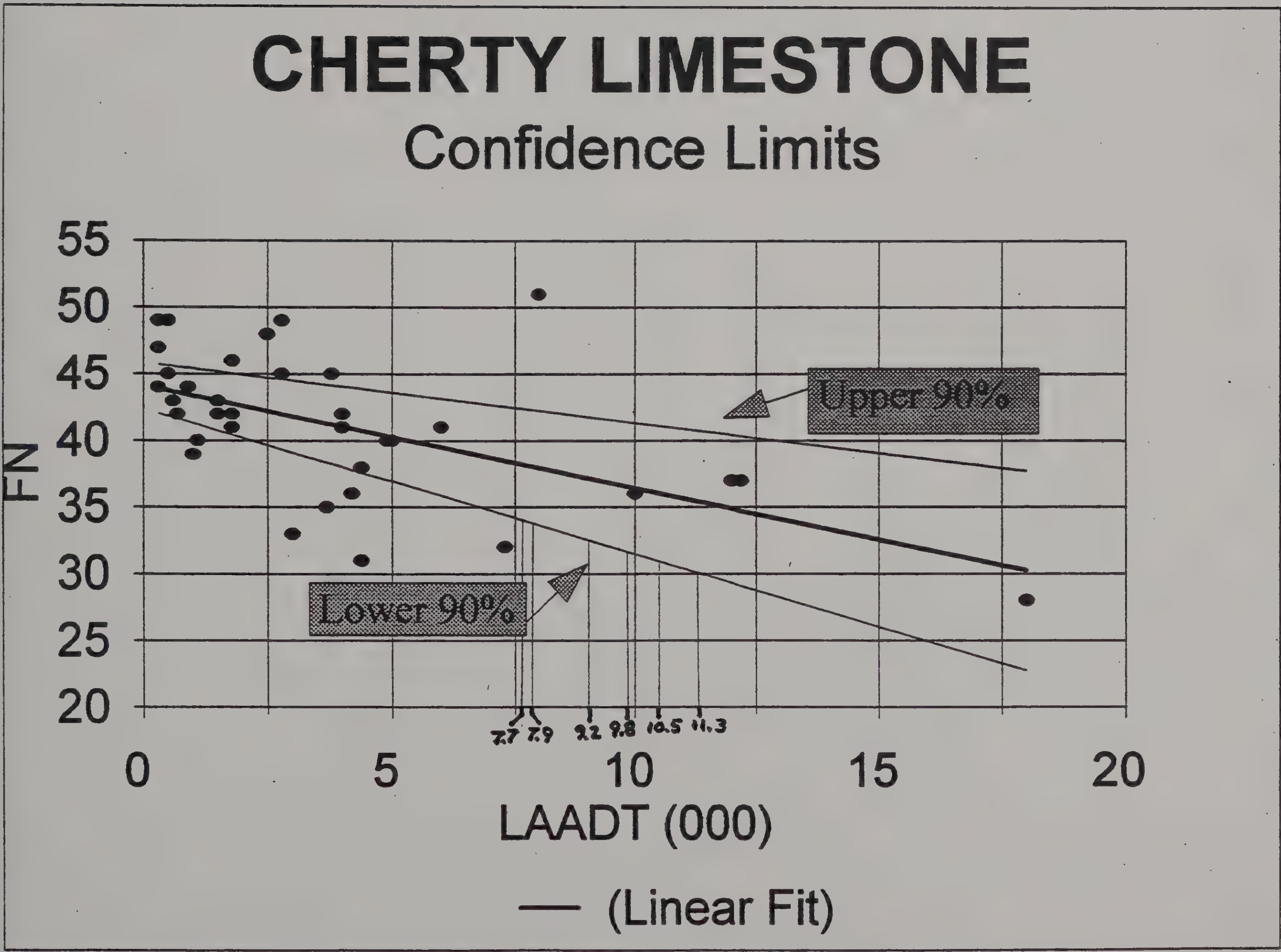


Figure B-2

AVERAGE FRICTION NUMBER vs

TRAFFIC INTENSITY (LAADT)

```
For MAFN determination for intersections IF-4,5, and 6:
IF-4   LAADT in zones 1 & 2= 9.8K   MAFN= 32
       LAADT in zone 4     = 11.3K  MAFN= 30
IF-5   LAADT in zones 1 & 2= 7.9K   MAFN= 34
       LAADT in zone 4     = 9.2K   MAFN= 33
IF-6   LAADT in zones 1 & 2= 7.7K   MAFN= 34
       LAADT in zone 4     = 10.5K  MAFN= 33
```



APPENDIX C

APPENDIX C

TEST BY REQUEST FRICTION DATA

Besides the data acquired through the testing of the nine intersections in the Study, additional data from tests by request (TBRs) were examined. This TBR data were originally obtained to learn about the performance of Wappinger Dolomite/ granite blends in high traffic volume applications. Friction tests were taken every 0.1 mile over the length of entire projects, and include curves, grades, merges, and intersections, as well as open road conditions. Although traffic volumes on these road sections are substantial, posted speeds are 40 mph or higher, and intersections are not closely spaced, allowing traffic to attain posted speeds between stops. Typical of these TBRs are two illustrated here (Appendix C). Friction testing was conducted in Lane 1 (of 2) in each direction. TBR 168 (Figure C-1 and Figure C-2) was a 3.4 mile long section of Rt. 9W in Orange Co., and includes three intersections and a merge from 4 lanes to 2. A sharp reduction in traffic volume from 6.6K vehicles per day to 3.3K occurs where Rt. 299 meets Rt. 9W at a T-junction, and about half the traffic leaves Rt. 9W . An increase in traffic volume from 3.3K to 5.5K occurs as a result of the merge. A trace of friction tests along the road section, with intersections and the merge identified, show that these features are reflected in the measured friction. MAFNs for each traffic volume are shown as well. In this case, the drop in friction at the intersections and at the merge do not fall significantly below the MAFNs, nor do they fall below the PDTM. The importance of these plots lies in that they show that pavement friction responds to intersections and to changes in traffic volume.

The second pair of illustrations is of TBR 171 (Figure C-3 and Figure C-4). Friction testing was conducted in Lane 1(of 2) in each direction. TBR 171 was a 4.5 mile section of Rt. 22 in Westchester Co., and includes three intersections interspersed with curves. The plots are annotated to show the locations of each of these features. Also shown is the MAFN for this traffic volume. As with TBR 168, the plots illustrate the friction drop in response to each of these features. In this TBR, as with the previous, the friction was above the PDTM throughout the section.

Figure C-5 shows a profile of lane 1, between mile-markers 1120 and 1129 on Rt 9 in Poughkeepsie. This illustrates true “open road” conditions leading into are series of signalized intersections. Friction measurements were taken every 0.1 mile. Both entry and braking zones are marked off before the first intersection at MM1126. In addition, the MAFN for a blend of Wappinger Dolomite and granite (approx. 35% non-carbonate) with a traffic volume of 9.5K (LAADT) was added for comparison. This profile illustrates the relationship of “open road” friction and intersection area friction with MAFN, at this site.

Figure C-1

FRICTION PROFILE

Route 9W, TBR 168, Northbound

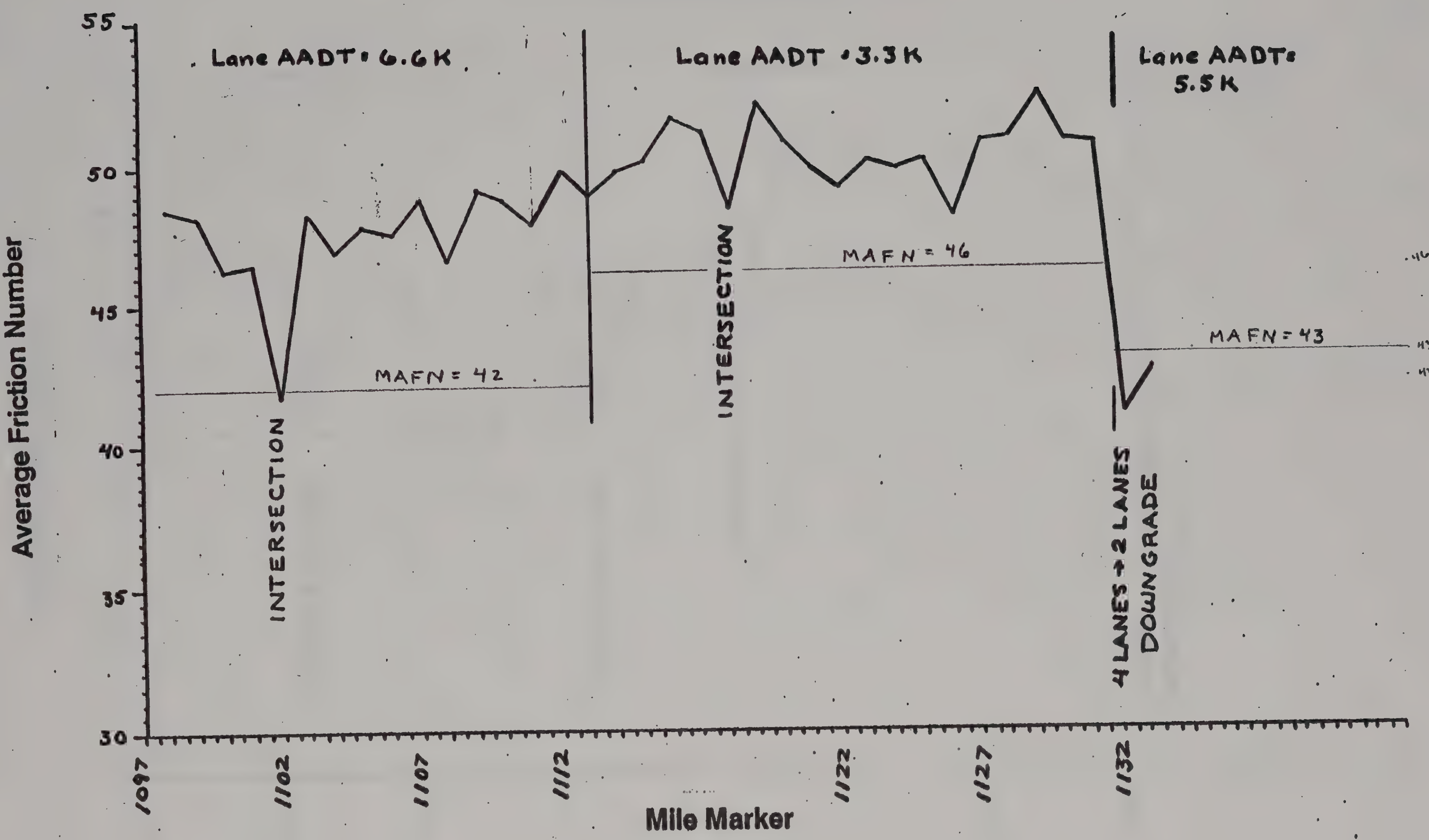
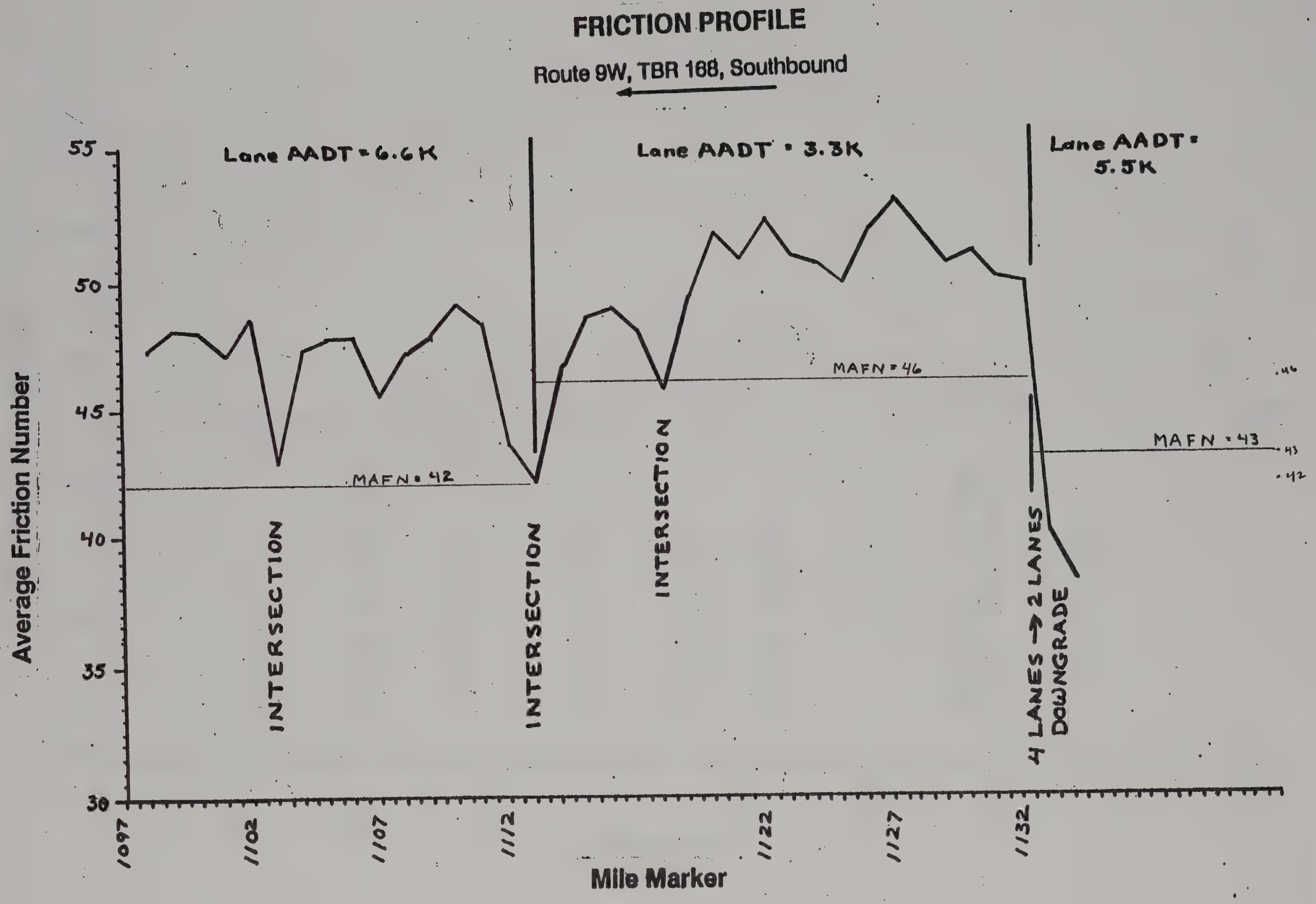


Figure C-2



FRICTION PROFILE
Route 9W, TBR 168, Southbound
Lane AADT = 6.6K
Lane AADT = 3.3K
Lane AADT = 5.5K
MAFN = 42
MAFN = 46
MAFN = 43
INTERSECTION
INTERSECTION
INTERSECTION
4 LANES → 2 LANES
DOWNGRADE
Average Friction Number
55
50
45
40
35
30
1097
1102
1107
1112
1122
1127
1132
Mile Marker

Figure C-3 **FRICTION PROFILE**

Route 22, TBR 171, Northbound

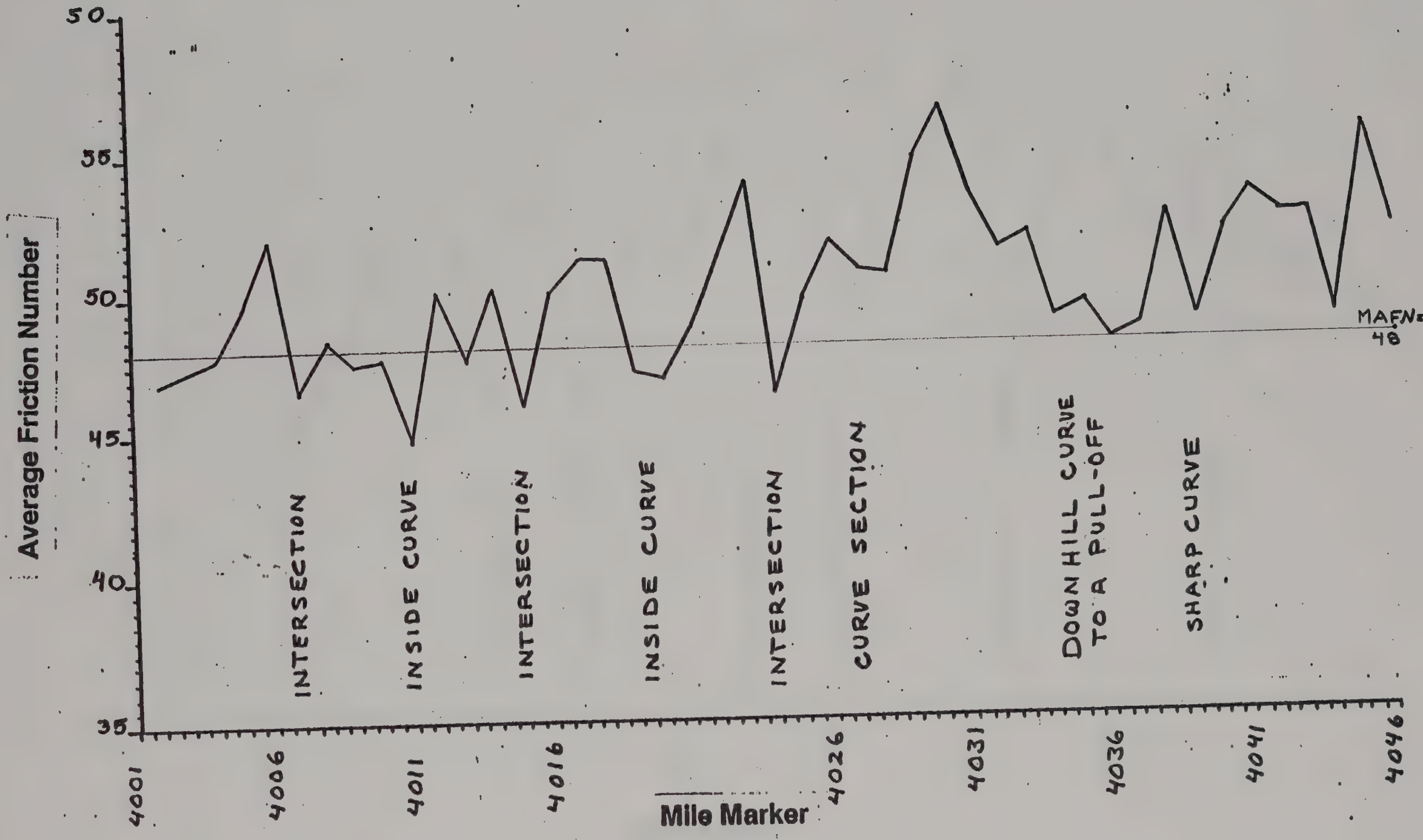


Figure C-4 **FRICTION PROFILE**

Route 22, TBR 171, Southbound

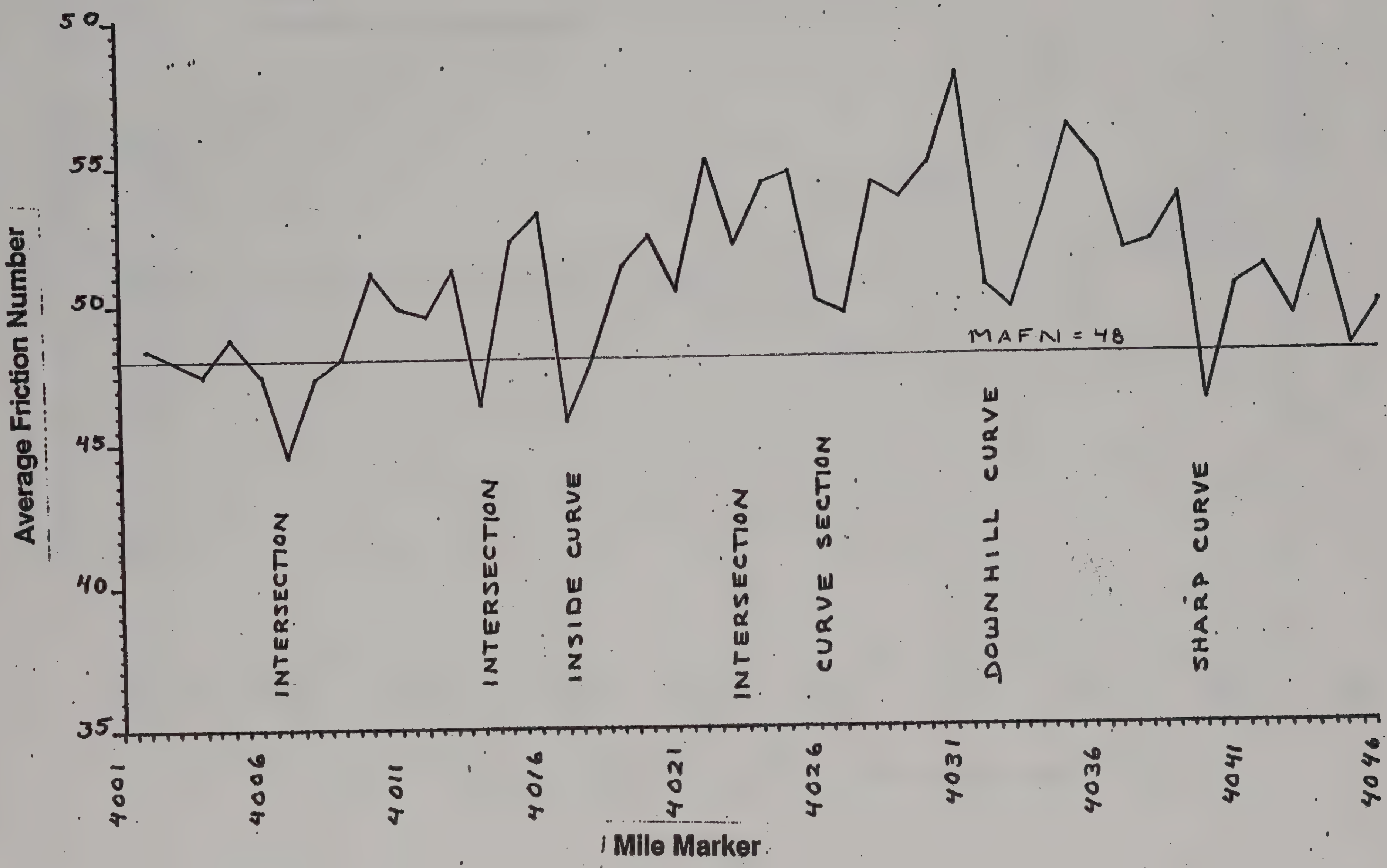
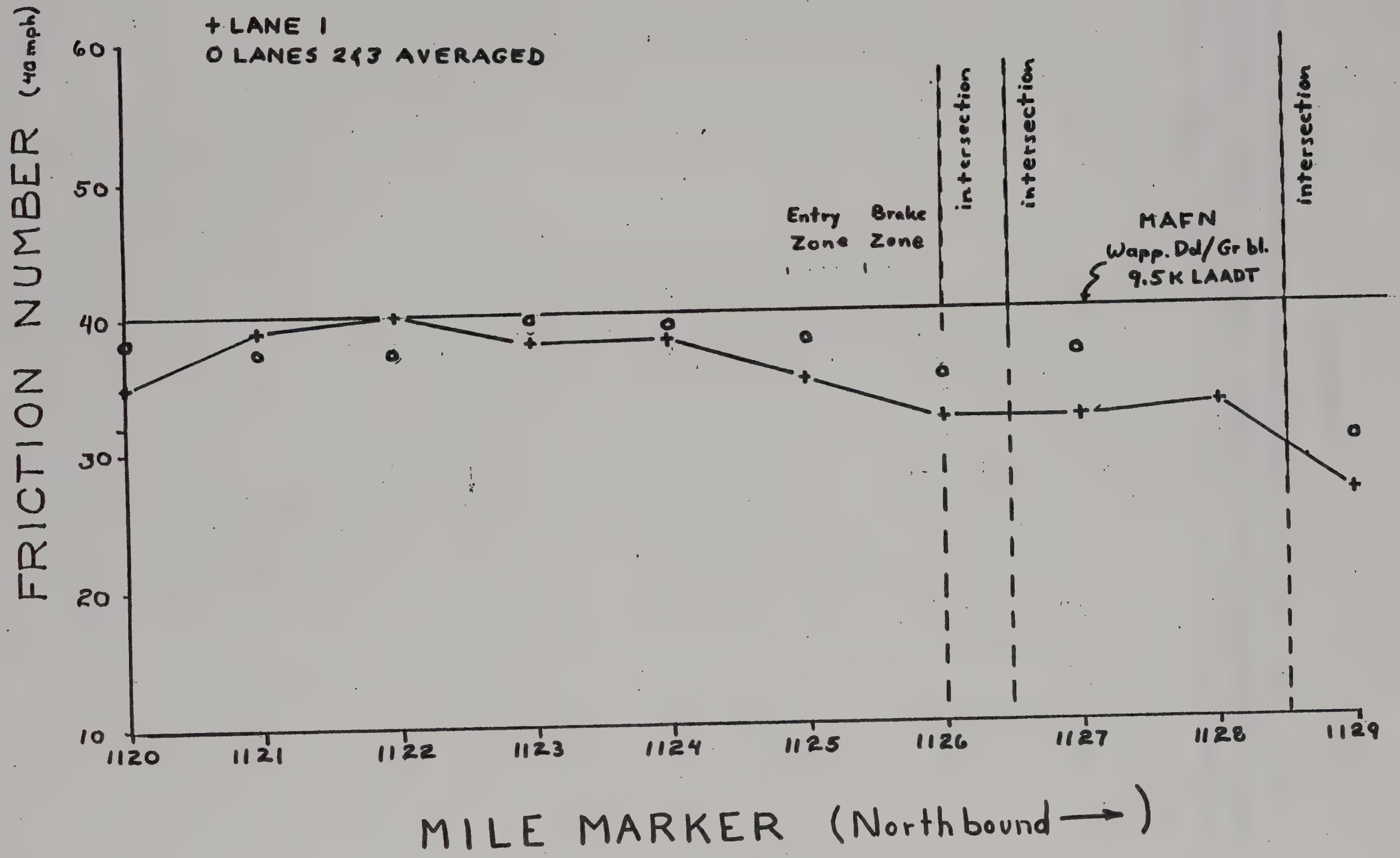


Figure C-5: FRICTION PROFILE

RT 9 NORTHBOUND LANES →



APPENDIX D

This appendix contains a Department memorandum, dated January 9, 1997, that recommends three levels of action to be taken in response to the results of friction testing priority investigation locations (PILs). Sites are designated PILs when the accident rate at that location is significantly above the statewide average.

MEMORANDUM
DEPARTMENT OF TRANSPORTATION

TO: Regional Director, Region ____

FROM: T. C. Werner, Traffic/Planning Division, 5-312 JSB
P. J. Mack, Technical Services Division, 7A-210 PJM

SUBJECT: WET ROAD PIL's (FRICTION TESTS)

DATE: January 9, 1997

In response to a recent significant pavement friction problem, the Traffic/Planning and Technical Services Divisions established a set of policies/actions to ensure that a similar problem does not occur in the future. One action was to friction test each year all highway locations which appear on the Department's Wet Road PIL listing. Friction tests for the first year of this initiative (1996) are complete. A copy of the test results for your Region is attached. We have also attached a summary table of the results ranked in accordance with proportions of test results below 26, between 26 and 32, and none below 32.

Whenever it is determined (through engineering judgement and/or friction tests) that roadway surface conditions are contributing to unusually high rates of wet road accidents, prompt remedial action is highly recommended. Based on a review of the literature and our own experience in friction testing, we have agreed upon some guidelines which should assist your Region in making decisions to address low friction numbers.

RECOMMENDED ACTIONS

o When 33% or more of the FN (40) friction test results within the Wet Road PIL segment are below 26, remedial action should be scheduled as soon as possible to improve the frictional quality of the pavement segment. In most cases the entire segment should be treated. However, it may not be necessary to treat lengthy sections (within the segment) that have FN(40) test results above 32.

o In all other instances where FN(40) friction test results are below 32, the Wet

Road PIL location should be evaluated as soon as possible to determine if friction is contributing to skidding accidents. If it is determined that pavement friction is a major contributor to the accident problem, remedial action should be scheduled as soon as possible to improve the frictional quality of the pavement for the entire Wet Road PIL, or the portion(s) of the pavement which is contributing to the skidding problem.

o When all FN(40) friction test results within the Wet Road PIL are 32 or higher, Friction, by itself, is not the likely cause of the wet road accident problem. In those instances, other roadway and operational characteristics should be investigated to find a solution to resolve the accident problem. If it is determined that, in order to address the accident problem, the frictional qualities of the pavement should be improved to a higher level than normally required, consideration should be given to improving the frictional qualities of the pavement.

These action thresholds are based on the most current research on correlations between FN(40) friction numbers and surface related wet road accidents. The recommended actions do not preclude other appropriate temporary actions, such as signing or speed limit changes, etc. designed to address the accident problem until the pavement surface has been remediated.

We recognize that final determinations as to which sections of roadway should be treated to improve friction reside with the Regional Director. However, In considering these guidelines in making your decisions, it is important to understand that any low friction numbers which occur at these tested highway sections, are occurring at locations which are also experiencing exceptionally high wet road accident rates. They have, therefore, met two objective tests indicating a possible surface related problem (low friction, and high wet road accidents).

If you have any questions regarding the wet road PIL friction testing program, these guidelines, or appropriate treatments, please contact Jon Bray (457-3537) on traffic safety issues, or Bill Skerritt (457-1038) on friction testing and materials issues.

BWS:JSB:slf

Attachments:

cc: B. W. Smith, Safety Program Management Bureau, 5-314
W. J. Brule, Materials Bureau, 7A-210

Figure B-3

AVERAGE FRICTION NUMBER vs

TRAFFIC INTENSITY (LAADT)

```
For MAFN determination for intersection IF-7:
IF-7   LAADT in zones 1 & 2= 6.6K   MAFN= 44
       LAADT in zone 4     = 8.9K   MAFN= 40
```

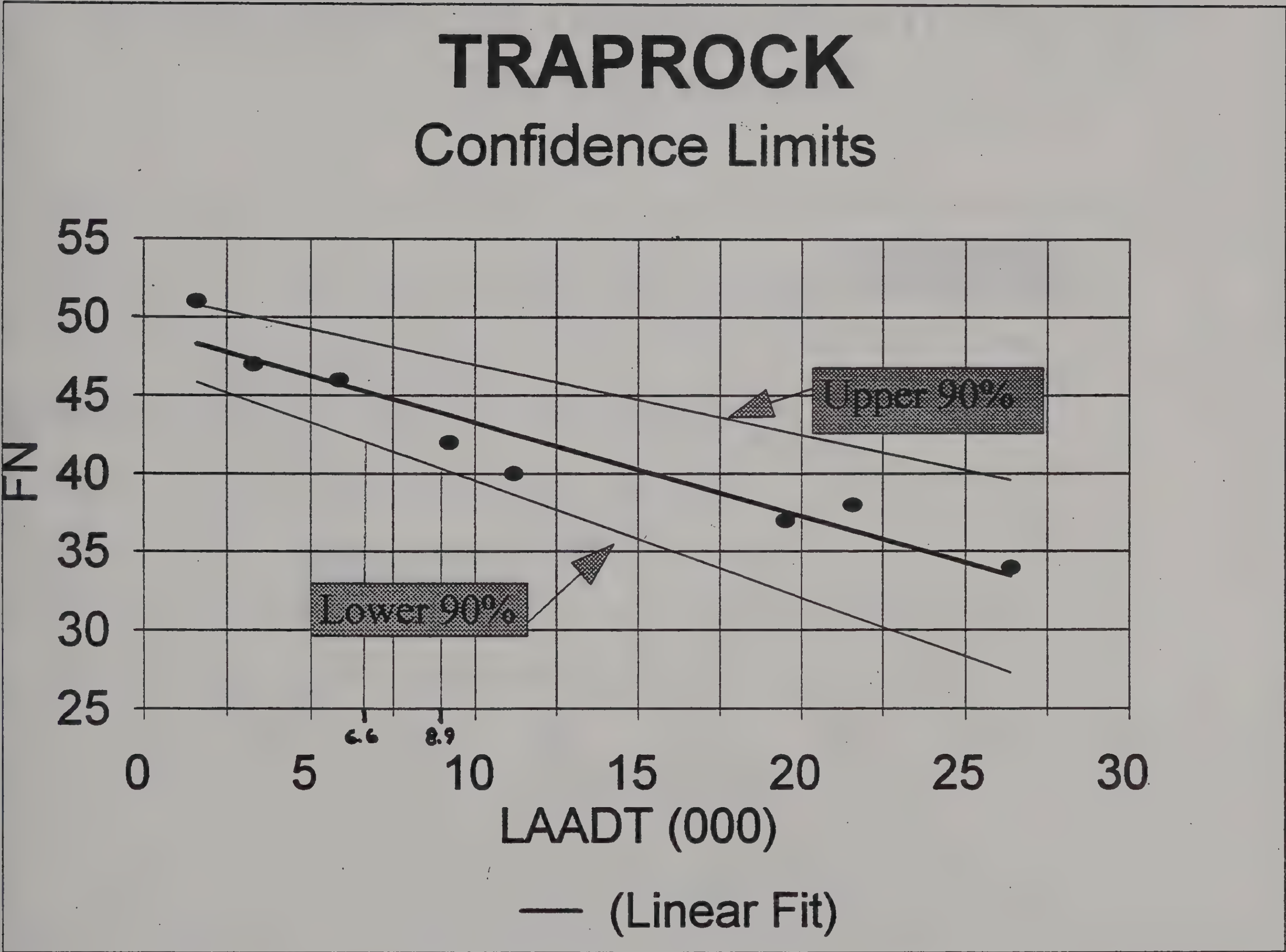


Figure B-4

AVERAGE FRICTION NUMBER vs

TRAFFIC INTENSITY (LAADT)

```
For MAFN determination for intersection IF-8:
IF-8   LAADT in zones 1 & 2= 3.5K   MAFN= 44
       LAADT in zone 4     = 4.3K   MAFN= 42
```

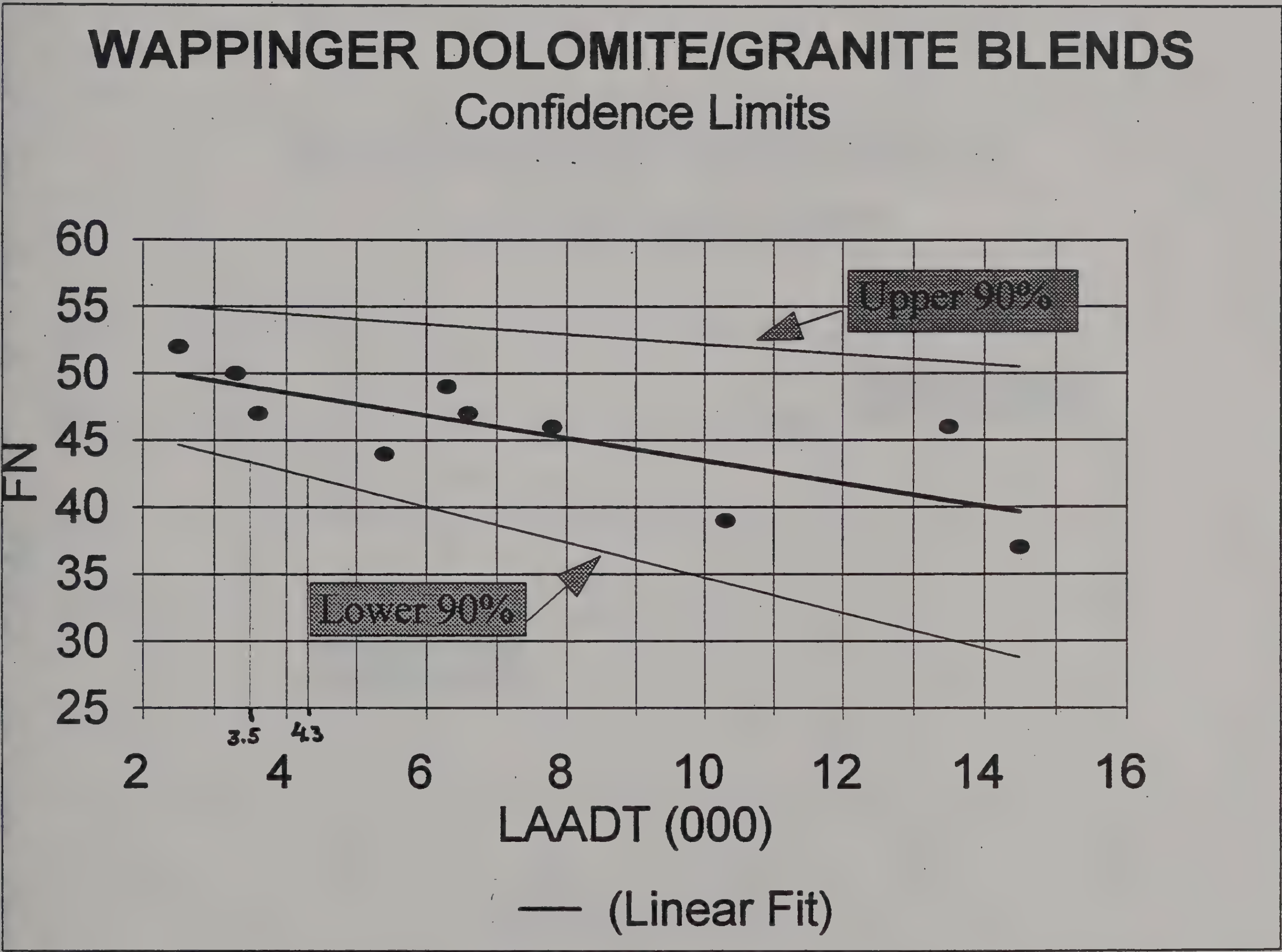


Figure B-5

AVERAGE FRICTION NUMBER vs TRAFFIC INTENSITY (LAADT)

```
For MAFN determination for intersection IF-9:
IF-9   LAADT in zones 1 & 2= 6.1K   MAFN= 29
       LAADT in zone 4     = 7.6K   MAFN= 28
```